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GEOLOGICAL MAGAZINE

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The Small-scale Structures of South-Eastern Cowal, Argyllshire

By BASIL C. KING AND NICHOLAS RAST

ABSTRACT

Study of the small-scale structures of South-Eastern Cowal provides information about the movement history in an assemblage of grits and slates wherein the original sedimentary structures and textures are discernible. A sequence of folds of both Caledonoid (NE–SW) and cross-fold (NW–SE) axial directions can be recognized, with corresponding successive cleavages or schistosities. In the rocks of higher metamorphic grade towards the axial region of the Cowal anticline the earlier structures are largely obscured by recrystallization.

I. INTRODUCTION

DETAILED study of small-scale structures during mapping by the writers of selected areas of the Central Highlands has revealed an extraordinary complexity of fold movements, including folding along axial directions at right angles to the familiar " Caledonoid " folds (King and Rast, 1955). In general, however, the rocks in these areas are so strongly recrystallized that recognition of earlier structures, including those due to original sedimentation, is difficult and often impossible.

Comparison with formations in a lower grade of metamorphism was clearly desirable and an obvious choice of terrain was the Cowal area, not only for the admirable exposures provided by the extensive coastal sections, but also because of the detailed study of the small-scale structures by Clough recorded in the Cowal Memoir (1897), a study that remains as yet unsurpassed despite the wealth of subsequent literature on the Scottish Highlands.

In the present account Clough's analysis of the structural history of the rocks is largely confirmed, but it has been found that even in this terrain " cross-folding " on axes approximately at right angles to the main Caledonoid folds is ubiquitous. Moreover, a sequence consisting of a repetition of folding on both these axes can be clearly recognized. It is indeed, quite extraordinary that the cross-folding, which can be seen in almost every exposure from Innellan to Ardentinny, and again

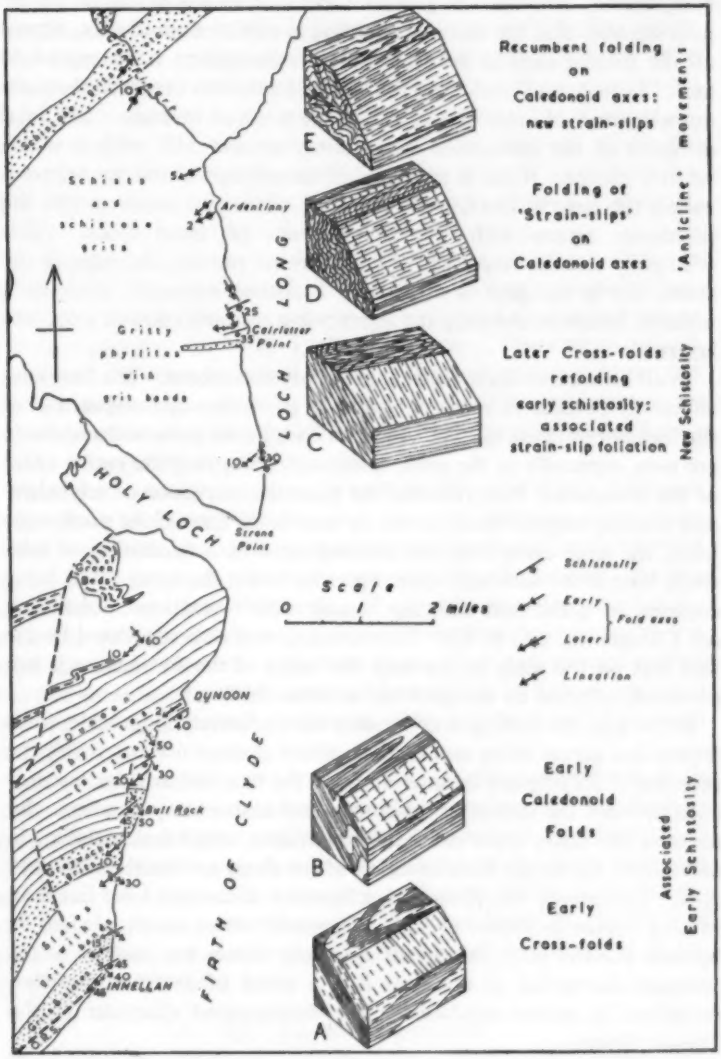
on the north-west side of the Cowal anticline along the shores of Loch Fyne, should have for so long remained unrecorded. Curiously enough undoubted cross-folds have been described and figured without the realization that they were not on Caledonoid axes (cf. Clough, op. cit., Fig. 11 and p. 59). It seems likely that Clough's unconventional use of the term " fold axis " (op. cit., footnote to p. 10) has contributed to the confusion. He used it to signify the line on the axial plane which is at right angles to the hinge of the fold.

The small-scale structures are readily appreciated in a traverse from Innellan along the western shore of Loch Long to Ardintinny, and thence along Glen Finart towards the axis of the Cowal anticline (see map, Text-fig. 1). The precise mode of development of the complex structures which are already established at Innellan is a matter of inference. Northwards, however, all stages can be recognized in the evolution of new structures successively superimposed on the older. Marked differences in tectonic style are revealed by formations of differing lithology.

Between Innellan and Dunoon the formations represented are phyllites, often slates, and grits of greywacke type, varying in grain-size. Towards Innellan the two formations alternate rapidly, but around Bull Rock there are extensive developments of massive pebbly grits, whereas around Dunoon phyllites (slates) predominate. Exposures round the Holy Loch are poor and intermittent, but they become frequent again northwards to Gairletter Point and Ardentinny. Along this section of the shore the lithology is fairly constant, with rapidly alternating grittier and more phyllitic bands, rocks of intermediate character being abundant. The grade of metamorphism is distinctly higher than at Dunoon and occasional flakes of biotite make their appearance. Inland from Ardentinny along Glen Finart the grade of metamorphism increases fairly rapidly. The rocks become increasingly schistose, biotite being conspicuous and albite appearing in certain bands.

II. Early Structures

These are most clearly displayed in the shore section from Innellan to Dunoon, from which they will therefore be described. They remain readily discernible, however, as far north as Gairletter Point. The form of the outcrops is determined by a strongly developed schistosity, virtually a cleavage in the argillaceous rocks. The strike of the schistosity varies around 40° or 50°, while the dip shows greater variations, but is often about 35° to 45°. In almost all rock types, with the exception of some of the more massive and uniform grits, the original sedimentary bedding can be recognized and on a broad scale the schistosity and bedding are approximately coincident. Graded bedding is common in



TEXT-FIG. 1.

the grit bands and shows frequent reversals in direction of " younging". The slates often show a very fine scale colour banding, due to slight sedimentational variations. The grits frequently contain slivers and small flat pebbles of slate, grey to black in colour.

Folding is ubiquitous and can be recognized on all visible scales.

Nevertheless, although the general disposition of the formation on the map suggests that the dominant folding is on Caledonoid axes, almost all the folding seen in the Innellan-Dunoon section is on cross-fold axes. Indeed, no Caledonoid folds at all have been observed throughout a distance of more than a mile to the north of Innellan. The axial direction of the cross-folds is uniformly around 140° with a south-easterly plunge. It lies in the plane of the schistosity and has approximately the same inclination (Text-fig. 1A). It is thus apparent that the schistosity agrees with the axial planes of these folds. This schistosity consists essentially of a mechanical parting (cleavage) in the slates, but in the grits is marked by a distinct mineral " platiness ", without, however, showing any appreciable concentration of mica into layers.

In all formations these folds are strongly recumbent. The limbs are effectively parallel to each other and to the large-scale disposition of the formations (Text-fig. 2A). Folds of considerable size and amplitude are seen, especially in the grits, sometimes occupying the entire width of the foreshore. Nevertheless, the general accordance of schistosity and bedding suggests that, as may be seen in the case of the small-scale folds, the large cross-folds are characterized by a succession of relatively long limbs with very short opposite limbs, the latter often being complex in detail and showing considerable formational thickening (cf. Clough, op. cit., p. 13). This conclusion is also supported by the fact that on the scale of the map the trend of the formations is not obviously affected by the presence of cross-folding.*

In the grits the folding is commonly on a relatively large scale, folds several feet across being usual. Even where closures are not visible the presence of folding can be inferred from the frequent angular discordance between the strikes of schistosity and sedimentary banding. By contrast the slates show exceedingly intricate, small-scale folding, in addition to the larger folds revealed where slates are interbanded with grits. Commonly the planes of schistosity (cleavage) have acted in varying degree as planes of slip. Especially where bands of slate lie between massive grits, movement along slip planes has resulted in the complete disruption of the slate into a series of detached lenticles, variations in colour emphasizing the disconnected character of the tectonic slivers.

Highly complicated structures are seen where alternating bands of grit and slate are involved in folds (Text-fig. 2B-D). The cleavage in the slates varies in intensity according to location with respect to the grit bands and often shows local deflection (Text-fig. 2D). The slates,

* It may be noted, however, that the form of the outcrops of " Green Beds " to the north-west of Dunoon suggests that here the cross-folds have a larger scale significance.

disrupted into lenticles along slip planes, show varying degrees of migration from their original positions. The lenticles apparently become isolated by obliquely intersecting planes, in which not only cleavage, but original bedding is often represented. The thinner bands of grit in fold closures may also be represented by a series of phacoids, but these retain their original relative positions, between which the slates often show tectonic intrusion (Text-fig. 2c). In some cases the closures of compressed folds in the grits have been isolated by shearing and semi-plastic movement in the surrounding slates.

Proceeding northwards the first recognizable Caledonoid folds are encountered a short distance south of the Bull Rock exposures (" Early Caledonoid Folds " in Text-fig. 1b). They show axial directions at 235° with plunges of 5° to 10° to the south-west. The same exposures also reveal the ubiquitous cross-folds. The relationship between the two sets of folds is not easily understood, for their axial planes are apparently coincident and the schistosity, which is quite unfolded, can equally be regarded as related to either set.

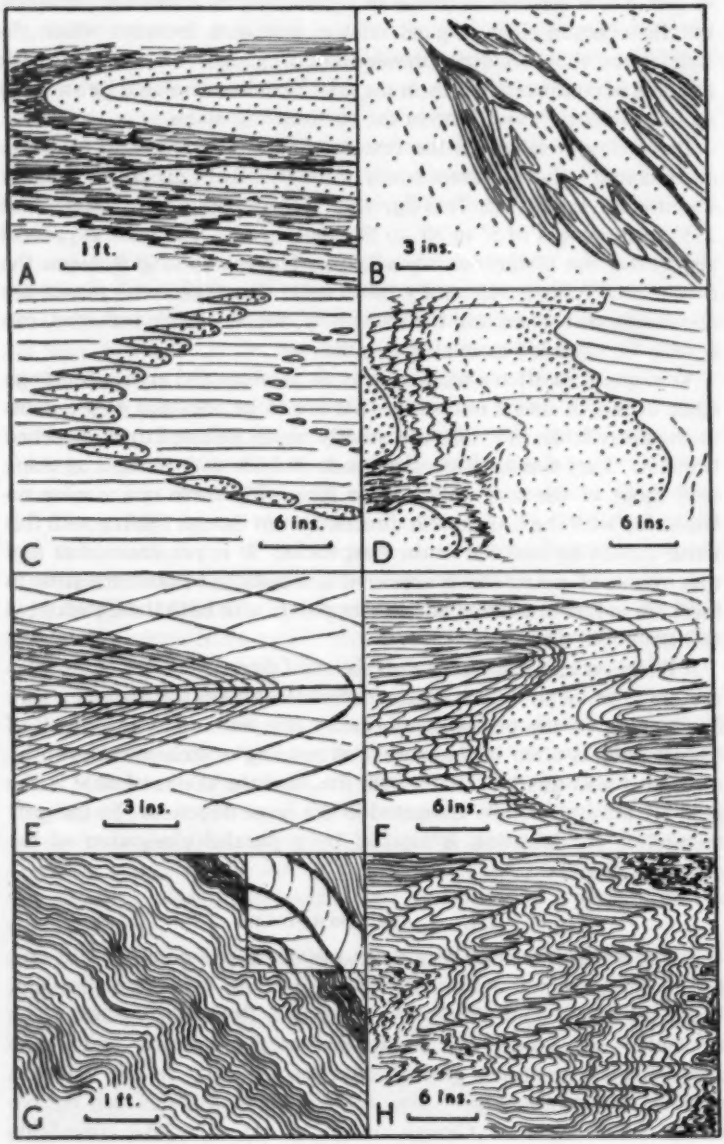
Vein quartz is often abundant in both phyllites and grits. Although some occurs in sheets following what are to be regarded as a-c joints to the cross-folds, the veins are usually highly plicated or in detached lenticles. Very common are small rods or folds with plunges agreeing with those of the cross-folds. Less frequently there is a similar relationship with the Caledonoid direction, even though folding with this trend cannot be detected in the host rocks. It is not unusual to find that masses of quartz which appear at first sight to be quite irregular in form are in fact orientated at different points with both the Caledonoid and cross-fold directions.

A lineation approximating with the axial direction of the cross-folds is often prominent. In the slates or phyllites it takes the form of a very fine ribbing on the planes of schistosity (the lines of " stretching " of Clough) and is often very apparent as rodding or striations shown by associated vein quartz. It is found, too, that the slivers of slate in the grits are always strongly elongated in the same direction. In the grits themselves the lineation is marked by a parallel elongation of the quartz grains (Text-fig. 1a).

III. Later Cross-folds

The first indications of later structures developed on cross-fold axes are minute crumples and broader undulations on the early schistosity. These are found sporadically from the Bull Rock northwards. The associated strain-slips are commonly steeply inclined and strike approximately with the general direction of dip. In the Dunoon phyllites apparently similar slips are sometimes found which behave like miniature faults (cf. Clough, op. cit., p. 11). The later cross-folds

are readily recognized since they refold the early schistosity. Even as far south as the Bull Rock there occur strongly recumbent cross-folds of this type. They appear to originate in open crumples of the kind already noted. Whereas the strain-slip associated with these crumples



is highly inclined to the early schistosity, the new axial plane schistosity that develops in relation to the later cross-folds is more nearly coincident with the early schistosity as preserved in unfolded layers. It seems likely that the second schistosity that is often seen in exposures from the Bull Rock northwards is related to this later folding, even where the folding itself cannot be recognized. Two schistosities, inclined at about 20° to each other are especially well exhibited by the Bull Rock greywacke. Of these, the steeper, later schistosity is accompanied by a micaceous layering.

In the shore section north of Gairletter Point an episode of later cross-folding can be shown to have affected the early schistosity. The earliest sign of the later folding around Gairletter Point is a marked lineation trending down the dip of the early schistosity at about 165°, which rapidly becomes a crumpling with a related strain-slip. This in turn passes into strong recumbent folding, the strain-slip being represented by a new axial plane schistosity which is effectively coincident with the earlier schistosity in unfolded layers. (Text-fig. 2E.) Where cross-folding of two episodes coincides in the same mass of rock the resultant structure is highly complex (Text-fig. 2F).

The most distinctive feature of the later cross-folding is the development of a strongly marked, though well-spaced micaceous layering in relation to the new axial plane schistosity. These layers have developed initially as strain-slips and partly owe the concentration of mica to the general principle observed by Clough (op. cit., p. 22) that " in thinned limbs the quartzose parts of the bands diminish in quantity, while the micaceous remain the same or increase ". Where first encountered the new strain-slips are widely spaced and often in pairs, defining layers of more quartzose composition than the bulk of the rocks, appropriately termed by Clough " strain bands ".

TEXT-FIG. 2.

A. Fold styles in alternating grits and slates, showing transitions to shears along schistosity. Folds plunge about 30° at 140°. Near Innellan.
B. Disharmonic folding between grits and slates. Near Innellan.
C. Bands of grit in slates showing development of phacoids parallel to axial plane schistosity : cross-folds. About 1 mile north of Innellan.
D. Grit bands showing graded bedding, interbanded with slates, and folded on cross-fold axes. The slates locally show tectonic intrusion into the grits. About 1 mile north of Innellan.
E. Grits showing later cross-folding with development of strain-slip foliation ; ½ mile north of Gairletter Point.
F. Grit band in slates illustrating effects of two episodes of cross-folding. The earlier schistosity has been folded and the new strain-slip foliation is developing parallel to the axial planes of the later folds. North of Gairletter Point.
G. Open folding on Caledonold axes of later strain-slip foliation. Inset shows earlier schistosity within strain-bands. Near Ardentinny.
H. Recumbent folding on Caledonoid axes affecting strain-slip foliation with development of new strain-slips. Ardentinny.

This later foliation, or micaceous layering, becomes the most obvious planar structure in relation to all subsequent movements, for it largely or wholly supersedes the earlier bedding and schistosity and, were it not that its mode of development can be precisely traced, could easily be mistaken for an original sedimentational layering. In the rocks of low metamorphic grade, which extend as far north as Ardentinny, the earlier schistosity can usually be discerned, inclined at varying angles to the new foliation or strain-bands (cf. inset to Text-fig. 2G and Clough, op. cit., Figs. 8–14).

IV. Later Caledonoid Folding (" Anticline Movements " of Clough)

A lineation agreeing with the axial direction of the Caledonoid folding is widespread and is developed sporadically on the early schistosity almost as far south as Innellan. This consists of tiny, discontinuous, asymmetric crumples and is conveniently referred to as a " phyllitic " lineation. In places it shows a greater amplitude and then displays a related strain-slip cleavage, which is often inclined nearly perpendicularly to the original schistosity. It seems likely that successive phyllitic lineations have been developed. At Gairletter Point, for example, two such lineations, inclined at a small angle to each other can be seen in the same exposures. Moreover, phyllitic lineations are commonly found on all the planar structures from the early schistosity to the latest strain-slips.

In a number of places between Bull Rock and Dunoon comparatively large, open or slightly recumbent later folds on Caledonoid axes are seen. Indeed, the variations in dip along this section of the shore may be regarded as folding of this kind on a larger scale. The visible folds are often rather irregular, or angular in profile, and generally plunge at low angles to the south-west. Sometimes they are represented by small, sinuous buckles, as in the Bull Rock greywacke, where they consist of narrow stripes a few inches wide in which the earlier schistosity shows a sharp deflection from the normal trend.

It is, however, towards Ardentinny that these later structures begin to assume major significance. Phyllitic lineations and undulations on Caledonoid trends are prominent even at Gairletter Point, but at Ardentinny the new strain-slip or foliation, related to the later cross-folding, is now strongly developed and becomes conspicuously folded on Caledonoid axes (sub-horizontal at 50° to 70°) (Text-figs 1D and 2G). Where the folds remain open and simple in form the axial planes are inclined at low angles (generally north-westwards) and are accompanied by a faint new strain-slip. Northwards the folds rapidly become more compressed and recumbent, but are highly distinctive in form, each major fold consisting of a complex of smaller folds, the profile of the

whole having the general shape of an oak-leaf (Text-figs. 1E and 2H). At Ardentinny the axial planes of the major folds are inclined to the north-west at low, but varying angles. The axial planes of the subsidiary folds commonly show even greater diversity of dip, although they all intersect in a common axial direction. Several strain-slips may correspondingly be found in the same complex fold, but generally only that related to the major axial plane persists into the core of the fold. As noted above even on these later strain-slips it is usual to observe a finely ribbed phyllitic lineation.

This sequence of events has been very fully described by Clough (op. cit., pp. 18–26), but he evidently failed to recognize that the folding by which the strain-slip foliation is produced was on axes at right angles (cross-folds) to those on which the foliation is subsequently folded (Caledonoid folds).

Inland from Ardentinny along Glen Finart the structures show no significant change for some miles, but the grade of metamorphism increases fairly rapidly. In consequence all the finer and earlier structures are obliterated so that in general the strain-slip foliation is the earliest structure that can be recognized. As the centre of the anticline is approached the later Caledonoid folds become strongly recumbent and compressed, the axial planes being sub-horizontal, but they often show more open flexuring with accompanying strain-slips at steep angles.

V. General Inferences

The chief episodes in the tectonic history of the area may be summarized as follows :—

(a) Folding on NW-SE (cross-folds) and NE-SW (Caledonoid) axes affecting the original bedding. The early schistosity is apparently similarly related to the axial planes of both sets of folds.

(b) An episode of later cross-folding, accompanied by the development of a strain-slip foliation.

(c) Folding on Caledonoid axes, with related strain-slips (the " movements of anticline age " of Clough).

Thus in individual outcrops examples may be found of Caledonoid folding either ante-dating or post-dating cross-folding, or again of folds on both axes which appear to be essentially contemporaneous. Inferences as to the relative age of the two directions of folding based on isolated observations might, therefore, be quite misleading. Although for descriptive purposes the terms Caledonoid and cross-folds are employed, more or less marked divergence of axial direction may be recognized in successive episodes of the same group of folds. Nevertheless, it is likely that the two groups of folds have different meanings in the movement pattern on a regional scale. This difference

may indeed be that which can be inferred directly from small-scale structures, for the cross-folds correspond to the general direction of elongation or transport, whereas the Caledonoid folds are more especially related to an axis of rotation.

The double system of folding, concerning the significance of which there has been so much controversy in the Moines of the Northern Highlands, has now been recognized over many parts of the Dalradian area of the Central Highlands (King and Rast, 1955). Recently, the presence of cross-folding in addition to folds on Caledonoid axes has been established by M. C. Vogt (1954), who recognizes the two sets not only from visible structures, but also from fabric analysis of the orientation of quartz grains. With the observation of such folding in the low grade metamorphic area of Cowal it seems probable that further study will show that cross-folding on some scale occurs throughout the region of the Scottish Highlands and that it is to be regarded as an integral part of the Caledonian movement pattern.

In the Cowal area the style of visible folds provides only limited information as to the extent to which a rock mass as a whole has been deformed, for the folding in each episode normally proceeds to recumbency and compression. Deformation must, however, increase with each successive episode of movement, but the earlier movement history is no longer recognizable even in the area of the Cowal anticline, so that over much of the Central Highlands, where recrystallization at high metamorphic grades is usual, it is likely that only the later fold movements can be recognized at all. On a regional scale the relatively regular disposition and persistence of formations in that part of the Highlands adjacent to the Boundary Fault suggests that the movement history has been less complex than in the Central Highlands, where the distribution of the various formations is very much more complicated. An important factor in this difference may be that, as shown in Cowal, the earlier visible folding is characterized by limbs of very unequal length, so that the folds only occupy limited parts of a particular layer of rock and folds of successive episodes rarely coincide. The major structures to which these visible folds correspond may, therefore, be comparatively simple folds.

Only during their initiation as open crumples do the visible folds appear to be purely flexural in origin ; as they attain recumbency so movement becomes dominated by shear parallel to the axial planes and long limbs of the folds, the latter showing attenuation of quartzose layers, with corresponding thickening in fold closures and in the shorter limbs. The distinction between flexural and shear-folding may thus be largely a matter of stage of development with regard to a particular fold.

As Clough (op. cit., p. 22) clearly appreciated physical strain

(deformation) of the rocks on a small scale varies very greatly from place to place even in the same exposure. This is most evident from the way in which earlier structures are preserved in layers of particular composition, or in particular parts of folds. There is, however, no simple relationship between grade of metamorphism and intensity of deformation and Clough's observations on this matter remain entirely relevant (op. cit., p. 22). He noted that on a small scale " greater metamorphism is shown along lines which have been specially subject to mechanical disturbance ". On a large scale there is also a very broad agreement between increase in metamorphic grade and the complexity of the tectonic history, both of which increase into the Cowal anticline. But there is no such correlation in greater detail. Thus metamorphism is of a distinctly higher grade at Gairletter Point than at Dunoon, but the structures show no significant advance. New structures are encountered rapidly towards Ardentinny, but the grade of metamorphism shows little change. Beyond Ardentinny, however, the grade increases rapidly, but there is no comparable increase in the complexity of the structures.

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Post-Palaeozoic Brachiopod Ecology : a Re-assessment

By G. F. Elliott

Abstract

Consideration of the field occurrence of certain post-Palaeozoic brachiopods, and of published experimental work on the transport of brachiopod shells by water, leads to the conclusion that these fossils are often deceptive as evidence of former conditions at the places where they now occur fossil, due to shell-transport by marine currents after death.

Introductory

EXCEPTING certain small brachiopods attached by cementation, such as *Crania* and most thecideans, and the burrowing *Lingula*, the vast majority of brachiopods since the Palaeozoic have been and are of rhynchonelloid or terebratuloid type, using the latter term broadly to include terebratelloids. So far as is known, these brachiopods are dispersed only in a very brief non-planktonic larval stage, and subsequently spend the rest of their life attached to foreign bodies by a non-calcareous pedicle, at varying depths in quiet waters suitable to this form of anchorage. Often they occur in patches of clusters showing several generations. It is thus reasonable to assume that like most "sessile benthos" they tend to be buried normally on the site of growth. The frequent presence of delicate calcareous brachial structures unbroken in suitably preserved fossils, and the fact that the shells, unless obviously *remanié*, are usually found bivalved and closed, and only exceptionally separate, broken, or worn, confirm this assumption.

Although assembly by current-action has sometimes been invoked as a possible explanation for terebratuloid clusters the view given above is generally held. Recent observations suggest however that in very many cases the occurrence of undamaged brachiopods is no indication of their having lived at that spot.

Brachiopods from the Great Oolite of Bath

During collection of brachiopods for a re-investigation of the development of *Hamptonina* (Moore, 1860 ; Elliott, 1950) Moore's bed 2 on Hampton Down, which he considered as an ancient reef, was seen to be a raggy limestone composed of ooliths, small fossils and calcareous debris with seams and pockets of ochreous material apparently due to weathering. Later collecting has confirmed that this deposit is not of reef origin : corals are very rare, and fossil remains are mostly small brachiopods and bryozoa, with molluscan and echinoid debris, suggesting current-accumulated material. The corals described by earlier authors (Tomes, 1885) came from the limestone below (Moore's bed 1).

The brachiopods from bed 2 were unworn and in good condition, and loose valves formed a very small percentage of the assemblage. They showed no evidence of selective sorting : *Hamptonina*, by far the most abundant, varied in length from 1 to 10 mm., and other, larger brachiopods also occurred. Although variable mineral incrustation and small size made successful dissection of the brachial loops difficult, a majority of the *Hamptonina* were evidently buried with the loop intact, yet the evidence of the bed in which they occurred suggested water-moved material.

In endeavouring to account for this phenomenon the writer recalled the experimental work of Menard and Boucot (1951). Working with brachiopod shells on sandy and gravelly bottoms in a hydraulic flume with which production of water-currents of different velocities was possible, these authors showed that the shells were often freely moved by gentle currents incapable of moving the underlying constituent grains of sand, due to the much lower effective density of the hollow water-filled shells, even when the actual weight of the shell is many times that of a sand grain. Specimens of the recent *Terebratulina septentrionalis* (Couthouy), a typical " terebratuloid " in shape, varying in length from 6·2 to 24·1 mm. were moved on a bed of sand-grains of an average diameter of 0·36 mm. by gentle currents of velocities of 11·7 to 15·1 cm./sec. No data are available on breakages of brachial structures during movement, but in small recent shells, with the organic content of the calcium carbonate not yet removed, in a waterfilled shell and with possibly the fleshy sheathing of the brachial loop not yet decayed, it is unlikely that many breakages would occur during gentle movement. Other points of interest to the palaeontologist are that a mixture of two species may be current-sorted into species rather than according to size or shape, depending on the respective effective densities—an important point when the known colonial habit of brachiopod species is remembered—and that the orientation of a small number of current-moved shells is random in relation to current-direction.

A search through literature on present-day calcareous sediments, to see if an analogue to the Jurassic bed exists, led to Hedley's account of Mast Head Reef, Capricorn Group, Queensland ; this furnishes an account of an environment which might almost have been written to account for the Hampton Down beds. In discussing the sea-floor outside the lagoonal reefs and islets he comments " The swift currents that rush through the Capricorn Islands remove the mud . . . The sea-floor over which we dredged in a uniform depth of 17–20 fathoms consisted of masses of living coral ; budding reefs in fact, with intervening spaces of coarse sand and gravel, and here and there dense beds of kelp " (1905, p. 461). From this sea-floor the brachiopods he

dredged (p. 467) were rare valves of a species of *Crania*, a rhynchonellid stated to be quite common growing on a bryozoan, and a dallinid terebratelloid, *Frenulina sanguinolenta*, which occurred " in profusion ". In the Jurassic bed, *Crania* sp. occurs rarely, rhynchonellids and bryozoa are common, and the dallinid terebratelloid *Hamptonina buckmani*, closely comparable in size and biological detail with *F. sanguinolenta*, occurs in profusion. Delicate *F. sanguinolenta* with unbroken loops are sometimes found in recent beach sand, having survived transport from off-shore.

Bed 2 at Hampton Down is therefore considered to indicate a similar shallow, warm-water accumulation of current-transported calcareous debris ; the brachiopods, although often preserved with brachial structures intact, are not found where they lived.

Brachiopods from other Localities

A review of some other formations which have yielded hollow brachiopods showing brachial structures shows that in few if any is there evidence that the fossils lived where now found. The Pleistocene Red Crags of East Anglia are current-bedded littoral or inshore accumulations of drifted shells, yet fine brachial preparations are known (e.g. *Terebratula variabilis* Sowerby from Waldringfield, Suffolk). In the Eocene London Clay loops of *Terebratulina wardenensis* Elliott sometimes show encrusting serpulae, and must have lain for some time before burial ; the spreads of this brachiopod at different levels probably indicate temporary interruption of sedimentation, and post-mortem drifting could easily have occurred on the slightly hardened sea-floor. The Cretaceous Upper Chalk, particularly the *mucronata*-zone of Norwich and elsewhere, has yielded many brachiopods filled with soft powdery chalk which is easily washed and cleaned away to reveal the brachial loops. Estimates of the probable depth of the Chalk Sea vary ; Oakley (1937) inferred a depth of 50–200 fathoms from the Norfolk *mucronata*-zone sponge assemblage, and quoted Gignoux's sponge-estimate of 160 fathoms for the corresponding horizon in North Germany. Menard and Boucot's experiments showed that some terebratuloids were moved by currents no faster than natural currents occurring at more than 1,000 fathoms depth in the Pacific ; it seems likely that many of the Norfolk fossils travelled some distance after death on the Chalk sea-floor. Finally the famous Lower Cretaceous sponge-gravel of Faringdon, Berkshire, which yielded brachial preparations for all growth-stages of *Gemmarcula aurea* (Elliott, 1947) is a current-bedded deposit in which 84 per cent of this species are worn disconnected valves. To account for the well-preserved and bivalved 16 per cent, the writer supposed that they were buried quietly on the site of growth. This view must now be abandoned,

and the whole deposit regarded simply as a current-accumulation of largely organic material on an irregular bottom in shallow water, as the rest of the evidence indicates.

The examples quoted are all of deposits where exceptional preservation permits profitable dissection of internal structures. However, it is probable that the ordinary matrix- or calcite-filled brachiopods from most levels would show a similar proportion of undamaged brachial structures. Occasionally silicification permits investigation through acid treatment : the brachial loops from the French Jurassic (Bajocian) figured by Arcelin and Roché came from a fine-grained yellow limestone. They record (1936, pp. 10–11) that the terebratuloids were bivalved, closed, and occurred with the brachial valve uppermost ; the rhynchonellid valves gaped and the shells lay irregularly. These observations suggest a random assemblage not on the site of growth.

Conclusion

It would seem that many brachiopods, although part of the sessile benthos and gregarious or colonial in occurrence during life, are frequently not representative of the former living fauna at the spot where they subsequently occur fossil. Post-mortem loss or decay of the organic anchorage or pedicle frees the thin light water-filled shell. At almost all depths suitable currents for transport occur, given a sea-floor of suitable grain-size and topography, and this is believed to have occurred extensively, unlike the theoretically possible but unproven transport of living brachiopods by scallops (Allan 1937). How far dead shells can travel under ideal conditions is not known, but frequently they do not show the signs conventionally considered to indicate such travel wear and tear, delicate structures broken, size-grading, majority orientation and even post-mortem concentration of shells of one species is possible on mechanical grounds alone. Indeed many deposits yielding exceptionally well-preserved material are current-accumulations, such preservation apparently depending on the different diagenetic history of these beds when compared with more normal fine-grained sediments. The scarcity of brachiopods in post-Palaeozoic reefs, ideal sites for preservation *in situ*, has been commented on elsewhere (Elliott, 1950).

These remarks apply to the terebratuloids and rhynchonelloids characteristic of the Mesozoic and Tertiary ; the larger and varied shells of the Palaeozoic have not been considered in this paper.

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Depth-Volatile Relations in Coalfields

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ABSTRACT

General considerations relating to the use of analyses for determining depth-volatile relations in coalfields are discussed. New evidence from New Zealand is presented and British evidence reviewed. A maximum rate of downward decrease of volatiles is inferred at 23 per cent volatiles, and a depth-volatile band from 42 to 5 per cent volatiles is presented. British coalfield sequences fit the band, rendering unnecessary the complex geological explanations for differing rates of downward decrease of volatiles given by previous authors. Tectonic pressure is rejected in favour of depth of burial as a cause of rank differences.

INTRODUCTION

A SERIES of papers discussing in detail the geological and economic implications of depth-volatile relations in coal seam sequences has appeared in the past seven years. Wellman (1948) interpreted the evidence in the Kent Coalfield as showing that the geothermal gradient at the time of maximum depth of burial increased two and a half times in a distance of seven miles. Trotter (1949) presented data from South Wales which he considered pointed to the existence of a major thrust beneath the coalfield, and which he used to predict volatile contents in unworked areas. Jones (1949) maintained that depth of burial, not tectonic movement, is the cause of devolatilization in all coalfields, and suggested that varying rates of decrease of volatiles with depth may be due to differing rates of sedimentation. Trotter (1950), while still considering tectonic movement to be the significant factor in devolatilization, emphasized the "minor variations in coal seam volatiles arising from differences in original composition of vegetation", and pointed out that these "variations lessen progressively if the coal seams become devolatilized". Wellman (1950), rejecting Trotter's hypothesis of a thrust as the cause of volatile distributions in South Wales, assumed differences of maximum depth of burial to be the cause, and deduced a geological history for the coalfield that required the deposition and later erosion of many thousands of feet of post-Coal Measures sediments. Jones (1951) also supported the depth of burial theory for South Wales, and deduced an empirical depth-volatile curve that provided more accurate estimates of volatile contents of seams in unworked areas than the mathematical relations of Trotter (1949) and Wellman (1950); his previous (1949) suggestion of the effects of rates of sedimentation was not mentioned.

The volatile contents of seams in the Kent and South Wales coalfields

range from 5 to 36 per cent, but Wellman (1948) extended his mathematical depth-volatile relationship to 50 per cent and Jones (1951) extended his empirical depth-volatile curve to 40 per cent. Trotter (1952) presented evidence for lower-rank (higher-volatile) " fat " bituminous coals, sub-bituminous coals, lignites, and peats, and inferred that, after a rapid downward decrease of volatiles within the peat itself, the average volatiles do not significantly alter during conversion of the peat to a " fat " bituminous coal (about 40 per cent volatiles) by depth of burial. In a recent paper (1954) he maintained that alteration of coal towards anthracite in the " High Rank Series " (less than 31 per cent volatiles) can be caused only by igneous intrusion, or tectonic forces, or both.

It is apparent that since coal is a sensitive indicator of changes caused by geologic factors, another tool would be available to the geologist for deducing the geological histories of coalfields provided that agreement could be reached on the interpretation of volatile differences.

During a study of the results of recent drilling in Greymouth Coalfield, New Zealand, the author noted that the widely different rates of downward decrease of volatiles appeared to be related to the range of volatiles in each sequence. This led to comparison with sequences in British coalfields, these also showing generally comparable rates of downward decrease of volatiles. In the present paper, discussion of general considerations too frequently ignored in studies of depth-volatile relations is followed by presentation of the Greymouth evidence and a review of the British evidence.

General Considerations

(*a*) The effects of coal type differences must be considered in any discussion of depth-volatile relations. The ranges of volatile content due to differences of coal type at different ranks have been discussed by Trotter (1952) and will be considered later in this paper. It may be noted here, however, that the effects of type can be so great that conclusions drawn from a few analyses only may be valueless. Either some adjustment for coal type should be attempted by making use of some other analytical determination, for example as Wellman (1952) used moisture, or the volatiles alone must be considered in relation to the extent of the differences that can arise from coal type.

(*b*) In discussing the volatile contents of coals of various ranges of rank, it is unsafe, owing to coal type differences, to compare coals of one age in one country with those of a considerably different age in another, as Trotter did in 1952. This is exceptionally well illustrated by New Zealand late Cretaceous and Tertiary coals, which fall in a band (for example on a chart with axes of carbon and hydrogen) that is parallel to, but at a higher hydrogen content than, the band for

British and North American Carboniferous coals, at least up to low volatile bituminous rank. The correspondingly higher volatiles of New Zealand coals make direct comparison with Carboniferous coals impossible.

(*c*) It is now generally accepted that it is unsatisfactory to compare volatiles on the dry ash-free basis, even though different formulae may be needed in the adjustment for ash and sulphur in different coalfields. For example for a 30 per cent volatile coal with 20 per cent ash, the dry ash-free basis gives 1·3 per cent volatiles more than the Parr mineral-matter-free basis. It is also probable that analyses of coal showing more than 20 per cent ash should be rejected altogether. Clearly the full proximate analyses should be published, but in their absence, for many of the areas discussed in this paper, the dry ash-free basis has been used in discussing British coalfields.

(*d*) Without adjustment of individual analyses for lateral rank variations, discussion of volatile contents of seams from other than vertical sections provided by shafts or bores [1] is practically valueless.

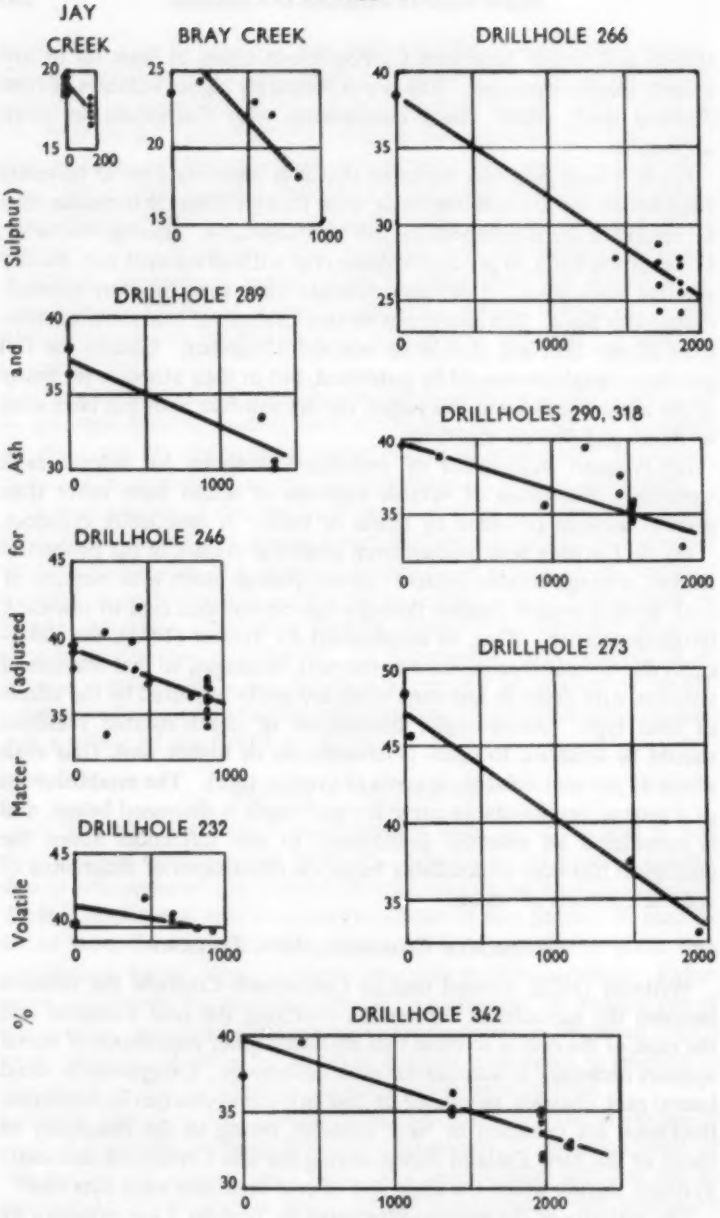
(*e*) As has long been known from graphical studies of the properties of coal, average volatile contents do not change much with increase of rank from low-rank lignites through sub-bituminous coal to low-rank bituminous coal. Also, as emphasized by Trotter (1952), the differences due to coal type increase as the rank decreases, so that changes of volatiles with depth in low-rank coals are easily obscured by the effects of coal type. Accordingly, discussions of depth-volatile relations should be confined to coals of bituminous or higher rank (less than about 42 per cent volatiles in coals of average type). The establishment of a general depth-volatile curve for such coals is discussed below, and is considered an essential preliminary to any inferences about the geological histories of coalfields based on discussions of differences of volatile contents of seams.

Greymouth Coalfield, New Zealand

Wellman (1952) showed that in Greymouth Coalfield the relation between the isopachs of formations overlying the coal measures and the rank of the coal is so close that no factor other than depth of burial appears necessary to account for rank differences. Exceptionally rapid lateral rank changes, paralleled by similarly rapid changes in formation thickness, are common in New Zealand, owing to the instability of much of the New Zealand region during the late Cretaceous and early Tertiary, during which the main sets of coal measures were deposited.

The majority of the sections illustrated by Text-fig. 1 are provided by

[1] The terms "borehole", "boring", "bore", and "drillhole" are commonly used with the same or closely similar meanings. In this paper "bore" is used in all cases.



TEXT-FIG. 1.—Changes of volatile content with depth, Greymouth Coalfield, New Zealand.

bores. Many samples were particularly high in ash, and only those with less than 20 per cent ash have been used in this discussion. Contamination of some bore samples, noted by Suggate (1955), may in a few cases have introduced small proportions of coal from higher seams. With one exception, where cuttings do not differ significantly from core, such minor contamination will have come from less than 120 feet above the seam, and errors will be negligible in comparison with the range of type variation expected within normal coals. The volatile contents have been adjusted first for water of hydration of the ash, using the factor 1·08 of the Parr formula, and then for sulphur on the assumption that the sulphur in the coal is a diluent that is entirely evolved as volatile matter.[1] The sulphur contents have not been determined for all samples but as they are closely related to stratigraphic depth below marine beds (Wellman 1952 : 98, 99), the assumption of values is unlikely to lead to serious errors. It is this relation of sulphur to stratigraphical position that makes it essential to consider the volatile contents on a sulphur-free basis.

The rates of decrease of volatile matter with depth are summarized in Table 1 :—

TABLE 1.—SUMMARY OF RATES OF DECREASE OF VOLATILES WITH DEPTH, GREYMOUTH COALFIELD.

Locality	*Reference to Coal Analyses*	*Average Volatile Content*	*Depth in feet per 1% decrease volatile matter*
Bore 232	Gage, 1952	41·0	570
Bore 273	Suggate, 1955	40·6	135
Bore 246	Gage, 1952	37·5	300
Bores 290, 318	Suggate, 1955	36·5	320
Bore 342	Suggate, 1955	36·5	300
Bore 289	Suggate, 1955	34·2	210
Bore 266	Suggate, 1955	31·3	150
Bray Creek	Gage, 1952	22·0	95
Jay Creek	Gage, 1952	17·9	105

Bore 232 : This bore penetrated the seam worked in No. 3A Section, Liverpool Mine ; an analysis of a sample from this seam, 300 yards from the bore, has also been used.

Bore 273.—The top samples are of thin bands of coal. Such bands are commonly of particularly high volatile types, as shown by com-

[1] A preliminary graphical study of the differences between analyses of high-ash and low-ash coals from the same locality suggests that the factor 1·08 is likely to prove generally satisfactory for New Zealand coals. The Parr basis for adjustment for sulphur, which assumes that all the sulphur is pyritic, is unsatisfactory for New Zealand coals in which almost all the sulphur is organic. Comparison of the analyses of high-sulphur and low-sulphur coals throughout New Zealand suggests that the method of adjustment for sulphur adopted here is substantially satisfactory.

parison with adjacent thick seams. This is certainly the reason for the exceptionally rapid rate of decrease of volatile content.

Bore 246.—This bore penetrated the seam worked in No. 3 Section Liverpool Mine, and analyses of two samples, 200 and 300 yards from the bore, have also been used.

Bores 290, 318.—Bore 290 was abandoned at a depth of 500 feet, and bore 318 put down about 150 yards away.

Bore 289.—No analyses from the top of this bore are available from bore samples, and those for North Brunner Mine, a little more than a quarter of a mile away, have been used. The stratigraphical position of the seam in the bore can be recognized to within a few feet. On the basis of the lateral isovol pattern at one coal-horizon (Suggate, 1955), the values assumed at the bore are 1·2 per cent less than those for North Brunner Mine.

Bore 266.—No analyses from the top of this bore are available from bore samples, and that of the adjacent seam at the entrance to Coal-pitheath Mine has been used. The stratigraphical position of this seam is only a few feet above the top of the bore.

Jay and Bray Creeks.—Outcrop samples ; some slightly weathered, but slight weathering is known to alter the percentage of volatile matter very little at this rank.

Establishment of the General Depth-volatile Band

The rate of downward decrease of volatiles in Greymouth Coalfield show a tendency to increase as the average volatiles for the sections decrease from 41 to 22 per cent, with the exception of bore 273 which, as mentioned above, is not unexpectedly an exception. A slight decrease in the rate from 22 to 18 per cent volatiles is also suggested. It was recognized that the information from Greymouth Coalfield alone is inadequate to establish these changing rates of downward decrease of volatiles, as only a few analyses are available for many sequences ; additional evidence was accordingly sought from British coalfields. Although exact comparison with British coalfields is not possible owing to the type differences between the New Zealand coals of late Cretaceous and Tertiary age and the British coals of Carboniferous age, a similar pattern of changing rate of downward decrease of volatiles might reasonably be looked for in sequences of comparable ranges of volatiles —parts of the Kent and South Wales coalfields, in the Pie Rough Bore in North Staffordshire, and in the Prestwich bores in Lancashire.

Kent Coalfield

Dines (1933) published the dry ash-free volatile contents of seams in seven vertical sequences in the Kent Coalfield. The figures are given to the nearest 1 per cent and it is not stated whether they are averages for

seams or individual analyses. He considered the distribution of volatiles, which lie within the range 35 to 12 per cent, to be unsystematic and inexplicable. Wellman (1958), appreciating that the different sequences showed greatly different rates of downward decrease of volatiles, suggested that this was the result of differences of metamorphic gradient, due to differences of geothermal gradient at the time of maximum depth of burial. In order to measure the metamorphic gradient he assumed a general relation between volatile matter and depth such that factor V_2 (volatile matter expressed as a percentage of fixed carbon) decreased logarithmically with depth, the depths in which the logarithm of V_2 decreased by unity measuring the relative metamorphic gradients of the different sequences. Even the largest differences can be thus explained, provided that the original geothermal gradient is considered sufficiently variable. For the Kent Coalfield, Wellman had to postulate a two and a half times increase in the geothermal gradient within a distance of seven miles. He extended his general relation between volatiles and depth to 50 per cent volatiles, the rate of downward decrease of volatiles decreasing as the volatiles decrease throughout the whole range of volatiles. This relation was used to calculate theoretical thicknesses of rocks deposited as part of the Coal Measure cycle of deposition, and eroded before the Mesozoic cover was laid down.

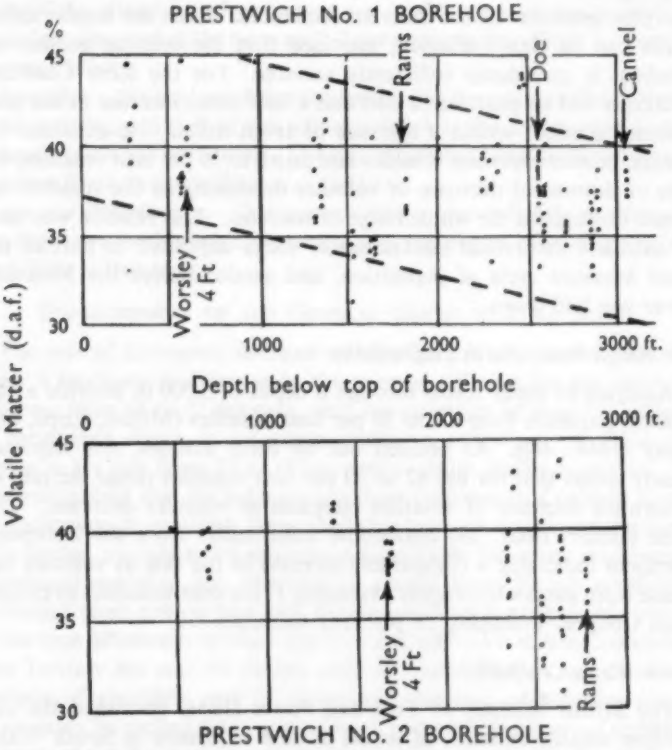
Pie Rough Bore, North Staffordshire

Analyses of many seams through a depth of 3,500 ft. provide a significant sequence from 42 to 30 per cent volatiles (Millott, Cope, and Berry (1946 : 40)). As pointed out by these authors, this sequence clearly shows that for the 42 to 30 per cent volatiles range the rate of downward decrease of volatiles increases as volatiles decrease. The same authors (ibid : 29) also quote information from the European continent indicating a comparable increase in the rate as volatiles decrease from gas coals (roughly averaging 37 per cent volatiles) to coking coals (roughly averaging 28 per cent volatiles).

South Wales Coalfield

The British Ministry of Fuel and Power (1946) published the dry ash-free volatile contents of seams in nine sequences in South Wales Coalfield, within the range 36 to 5 per cent volatiles. The analyses were given to the nearest 0·5 per cent and it is not stated whether they were averages for the seam or individual analyses. Trotter (1949) used the sequences to support his theory that the volatile content of any seam is related to the distance from a thrust plane beneath the coalfield, devolatilization of the coal being due to tectonic pressure ; a mathematical relation permitted the prediction of the volatile content of any

seam, knowing that of another seam in the same vertical sequence and the vertical distance apart of the two seams. Wellman (1950) used the same data to support a different mathematical relation between any two seams in vertical sequence, and suggested that depth of burial was the cause of devolatilization. Jones (1951), again using the same data, rejected the mathematical relations of Trotter and Wellman, as well as others that also generally fit the observed volatiles, and constructed an empirical depth-volatile curve which he extended beyond the 36 to 5 per cent range of observed values to 40 per cent ; he too considered depth of burial to have caused the devolatilization.



TEXT-FIG. 2.—Volatile contents of seams in Prestwich boreholes.

The mathematical relations of both Trotter and Wellman demand a decreasing rate of downward decrease of volatiles as volatiles decrease, and Jones's empirical curve shows a similar trend where the volatiles are less than 15 per cent. From 36 to 15 per cent volatiles Jones shows a uniform rate.

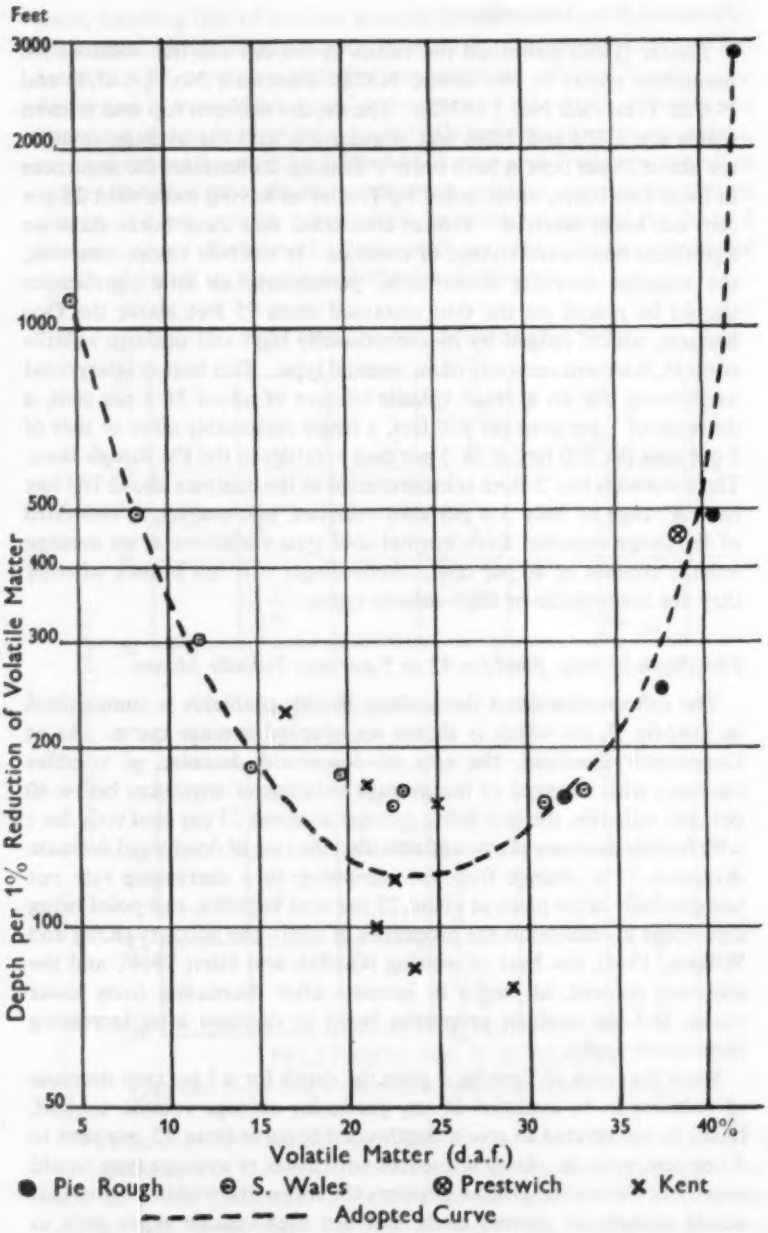
Prestwich Bore, Lancashire

Trotter (1954) published the values of the dry ash-free volatiles for numerous seams in two bores, N.C.B. Prestwich No. 1 (A1/1) and N.C.B. Prestwich No. 2 (A1/2). The depths between top and bottom seams are 2,770 and 2,298 feet respectively, and the average volatiles are about 38 per cent in both bores ; Text-fig. 2 illustrates the sequences in these two bores, coals noted by Trotter as having more than 25 per cent ash being omitted. Trotter concluded that these bores show no significant downward change of volatiles. In the No. 1 Bore, however, the volatiles decrease downwards, particularly as little significance should be placed on the thin unnamed seam 85 feet above the Doe horizon, which, judged by its exceptionally high and uniform volatile content, is almost certainly of an unusual type. This bore is interpreted as showing, for an average volatile content of about 38·5 per cent, a decrease of 1 per cent per 450 feet, a figure reasonably close to that of 1 per cent per 320 feet at 38·5 per cent volatiles in the Pie Rough Bore. The Prestwich No. 2 Bore is inconclusive as the analyses above 700 feet have a range of only 3·4 per cent volatiles, one-quarter to one-third of the range expected from normal coal type variations at an average volatile content of 40 per cent. Accordingly it is not known whether they are low-volatile or high-volatile types.

The Depth-Volatile Band for 42 to 5 per cent Volatile Matter

The information from the various British coalfields is summarized in Text-fig. 3, on which is shown an adopted average curve. As at Greymouth Coalfield, the rate of downward decrease of volatiles *increases* with decrease of the average volatiles of sequences below 40 per cent volatiles, the rate being greatest at about 23 per cent volatiles ; with further decrease of average volatiles, the rate of downward decrease *decreases*. The change from an increasing to a decreasing rate not unexpectedly takes place at about 23 per cent volatiles, this point being significant in relation to the properties of coal—the porosity (King and Wilkins, 1944), the heat of wetting (Griffith and Hirst 1944), and the moisture content, all begin to increase after decreasing from lower ranks, and the swelling properties begin to decrease after increasing from lower ranks.

Since the curve of Text-fig. 3 gives the depth for a 1 per cent decrease of volatiles to be expected at any particular average volatile content, it can be interpreted to give a depth-volatile curve from 42 per cent to 5 per cent volatile. Only sequences with coals of average type would exactly fit the curve, which represents the mean line within a band that would include all normal coals, but not high-volatile types such as cannels, or coals with unusual proportions of low-volatile constituents,



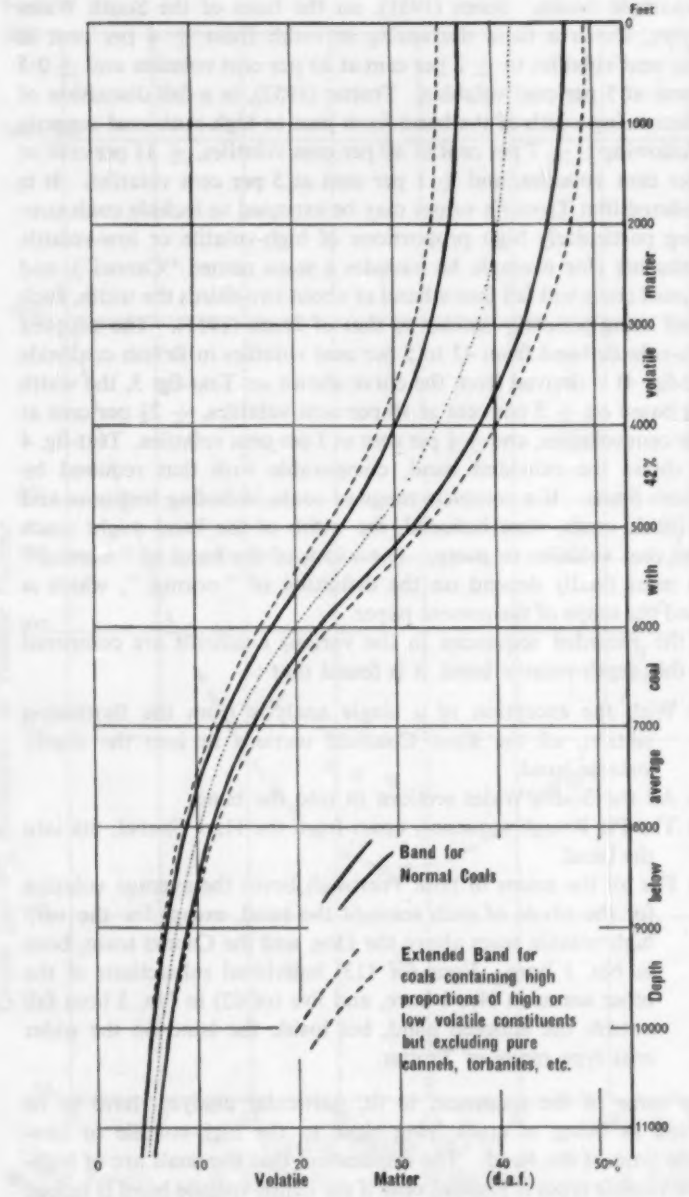
TEXT-FIG. 3.—Depth-volatile relations in British coalfield sections.

for example fusain. Jones (1951), on the basis of the South Wales analyses, shows a band decreasing in width from ± 4 per cent at 35 per cent volatiles to ± 2 per cent at 20 per cent volatiles and ± 0·5 per cent at 5 per cent volatiles. Trotter (1952), in a full discussion of the decreasing width of the band from peat to high rank coal suggests the following : ± 7 per cent at 40 per cent volatiles, ± 3½ per cent at 20 per cent volatiles, and ± 1 per cent at 5 per cent volatiles. It is considered that Trotter's values may be expected to include coals containing particularly high proportions of high-volatile or low-volatile constituents (for example he includes a seam named "Cannel"), and that most coals will fall into a band of about two-thirds the width, such a band being generally similar to that of Jones (1951). The adopted depth-volatile band from 42 to 5 per cent volatiles in British coalfields (Text-fig. 4) is derived from the curve shown on Text-fig. 3, the width being based on ± 5 per cent at 40 per cent volatiles, ± 2½ per cent at 20 per cent volatiles, and ± ¾ per cent at 5 per cent volatiles. Text-fig. 4 also shows the extended band, comparable with that required by Trotter's limits. If a complete range of coals, including torbanite and high-fusain coals, were included, the width of the band might reach 30 per cent volatiles or more. The width of the band of " normal " coals must finally depend on the definition of " normal ", which is beyond the scope of the present paper.

If the recorded sequences in the various coalfields are compared with this depth-volatile band, it is found that :—

(1) With the exception of a single analysis from the Barfreston section, all the Kent Coalfield sections fit into the depth-volatile band.
(2) All the South Wales sections fit into the band.
(3) The Pie Rough sequence, apart from the Hoo Cannel, fits into the band.
(4) For all the seams in both Prestwich bores the average volatiles for the whole of each seam fit the band, except for the very high volatile seam above the Doe, and the Cannel seam, both in No. 1 bore. Four (of 113) individual subsections of the other seams in No. 1 bore, and five (of 65) in No. 2 bore fall outside the adopted band, but inside the band on the wider coal type range of Trotter.

For some of the sequences to fit, particular analyses have to be accepted as being of coals lying close to the high-volatile or low-volatile limit of the band. The implication that the coals are of high- or low-volatile types is justified only if the depth-volatile band is indeed almost identical for all British coalfields and not merely an average. Any differences in depth-volatile curves for different coalfields, or even



TEXT-FIG. 4.—Depth-volatile band for British bituminous and anthracite coals.

within coalfields, could be attributed either to different tectonic histories if tectonic movement has caused devolatilization, or to different geothermal gradients during burial, if depth of burial has caused devolatilization. With difference of tectonic history, gross differences might be expected in the depth-volatile bands of different coalfields, but the author knows of no such proved gross differences. With differences of geothermal gradient, the depth-volatile bands are likely to differ far less, and the acceptance of the depth-volatile band of Text-fig. 4 does away with the need for Wellman's (1948) suggestion of a two-and-a-half times increase in the geothermal gradient in a distance of seven miles in the Kent Coalfield, an increase which seems geologically improbable. Differences of geothermal gradient between different regions may have existed and may have caused differences in the depth-volatile bands, but until sequences can be studied, either from a statistically large enough number of samples, or from a smaller number aided by petrological or rational analysis, such differences cannot be accepted as proved.

The Depth-volatile Band—A Function of Depth of Burial

The available evidence provides no alternative to a single depth-volatile band for all coalfields, implying a common cause of devolatilization. The principal disagreement as to whether this cause is tectonic force or depth of burial has related to the bituminous-anthracite range, depth of burial being generally conceded for lower rank coals. Trotter (1949, 1954) has provided the most detailed arguments in favour of tectonic force in the high rank range, and has presented evidence from which he concluded (1952, p. 138) that " the rise in rank from peat to fat bituminous coal is due essentially to loss of inherent moisture resulting from depth of burial of the seams by superincumbent strata ". He also considered that within the range of " fat " bituminous coals, volatiles show no systematic change with depth, but noted a decrease of moisture content.

Trotter estimated 6,000 to 7,000 feet for the depth between peat and " fat " bituminous coal. His information was drawn from North Dakota, Montana, New Mexico, and New Zealand, but a vertical sequence was available only from New Zealand where the Notown Bore, near Greymouth (see Gage, 1952) penetrated a seam of high-volatile butiminous coal at a depth of 6,893 feet. This bore has figured prominently in the recent papers on coal, Jones (1949), Trotter (1950), and Wellman (1950) accepting the geological inference that no more than 1,000 feet has been eroded from above the top of the bore. The interpretation of geological and geophysical work during the 10 years since the estimate was made has shown, however, that at least 3,000 or possibly as much as 5,000 feet of beds have been removed from above

the top of the bore. Since the coal at the bottom of the bore is of a high-volatile type (Wellman, 1950 ; 319 footnote)—and it may be added that the dry ash-free sulphur content of 6·3 per cent is a contributory factor in the high volatile content—exact comparison with British coals is impossible. It is probably, however, a low-rank bituminous coal generally comparable with a 40 per cent volatile British coal of average type. A depth of burial of about 10,000 feet seems probable for such a coal.

Trotter's (1952) evidence that within the " fat " bituminous coal range (over 37 per cent volatiles) " there is no significant loss of volatiles throughout another 7,000 ft. of strata ", based on stratigraphical, not vertical, sequences from Northumberland, cannot be accepted. Just as White (1915) and his followers failed to allow for vertical changes of volatile matter in seeking to establish lateral changes in the Appalachian region, so Trotter may well have failed to allow for the lateral changes in seeking to disprove vertical changes in Northumberland : Briggs (1923) has demonstrated significant lateral changes in volatiles in Northumberland.

An indication of the improbability of a 7,000 ft. sequence with no change in volatiles is given by the distribution of coals within the bands shown in studies of ultimate analyses such as those of Mott (1948). These bands show no excessive concentration of high volatile bituminous coals as would be expected if such a thickness of beds contained similar coals. On the contrary, Mott's evidence suggests that North American, British, and European coals are fairly evenly distributed along the band, and the volatile contents begin to decrease immediately with increase of rank beyond the boundary of sub-bituminous and bituminous coals. The New Zealand band, although derived from coals of different overall type, shows a similar even distribution of coals.

The cause of increase in rank towards anthracite has been argued at length by many authors, and it is not intended to reopen the discussion in detail. Trotter (1954) maintains that with coals of his " High Rank Series " (below 31 per cent volatiles), rank is "determined by and increases with the intensity of the orogenic forces and natural heat treatment to which the coal has been subjected ". The effects of igneous intrusion, where these are known or reliably inferred, cannot be doubted, but to consider orogenic forces the only other method of forming high-rank coals seems to be unrealistic. It can hardly be argued that to add an extra 5,000, 10,000 or 100,000 feet of sediments above 31 per cent volatile coal would have no effect.

In Greymouth Coalfield, coals that fall within Trotter's " High Rank Series " are not found in areas of greatest deformation, and the relation of the rank pattern to isopach patterns has been described by Wellman

(1952 : 95) thus : " The belt of highest rank coals coincides also in position with the mean position of belts of greatest thickness of formations from the Goldlight siltstone at least up to the Kaiata siltstone, and the gradual decrease of coal ranks westwards and rapid decrease eastwards from the maximum corresponds with the asymmetry of the isopach diagrams." It may be added that recent drilling (Suggate 1955) has confirmed this conclusion, and also suggests that a similar isopach pattern is not improbable for three formations of the coal measures below the Goldlight siltstone. There is no reason to postulate any explanation other than depth of burial to account for the high ranks of these coals.

If depth of burial can cause the high ranks in one coalfield, then only major differences from the depth-volatile band can justify other suggestions as to the causes of rank differences. The ideas of David White for the Appalachian region, the classic ground for the proponents of tectonic pressure as the cause of rank differences, have been strongly challenged by Heck (1943) who concluded that " the rank of the coal beds . . . is due to variation in the maximum depth of burial of those coal beds ". Of the 17 sequences quoted by Reeves (1928) for the Appalachian region, only one—that of the lowest rank coals with an average of 44·5 per cent volatiles—fails to fit the depth-volatile band of Text-fig. 4. This sequence is one of the least well controlled (" coals mined in adjacent localities "); it fits the wider band based on the coal-type band of Trotter.

Depth of burial is the simplest geological explanation, particularly since differences of depth, in all depth ranges, can scarcely be held to have no effect at all. There is no evidence that tectonic disturbance produces high temperatures, except in those layers immediately adjacent to faults of the greatest magnitude.

As an approximation, the depth of burial of bituminous coals and anthracites may be estimated from Text.-fig. 4, adding 7,500 ft. (10,000 ft. for the range from peat to 40 per cent volatiles minus 2,500 ft. for the 42–40 per cent volatiles range) to the depths shown on that figure. Some general agreement can be seen in the depths of burial suggested by different authors for different ranks, these being summarized below :—

Author	*Rank Range*	*Depth (ft.)*
Jones (1949)	Peat—40% volatiles	8,500
Wellman (1950)	Peat—lowest-rank bituminous	8,000
Trotter (1952)	Peat—low-rank bituminous	6,000–7,000
This paper	Peat—40% volatiles	10,000
Jones (1949)	Peat—5% volatiles	17,000
Wellman (1950)	Peat—4% volatiles	18,000
This paper	Peat—5% volatiles	19,000

Conclusions

(1) The general pattern of depth-volatile distribution for all coalfields shows an increasing rate of downward decrease of volatiles down to about 23 per cent volatiles, and a decreasing rate below 23 per cent volatiles.

(2) The differences of volatiles due to differences of coal type can be so great that explanation of different apparent rates of downward decrease of volatile involving differences in rates of sedimentation (Jones 1949) or of metamorphic gradient (Wellman, 1950), are unjustified.

(3) Depth of burial of about 10,000 ft. produces low-rank bituminous coal, and of about 19,000 feet produces a coal with 5 per cent volatile ; depth of burial is the cause of rank increase in all coalfields, except in areas of contact metamorphism.

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Preliminary Notes on the Geology of Kilimanjaro

By W. H. Wilcockson

(PLATES VII AND VIII)

Abstract

A preliminary account of the geological results of an expedition to the volcanic massif of Kilimanjaro is given. The structure and succession at each of the main eruptive centres is described. The probable ages of volcanicity are discussed.

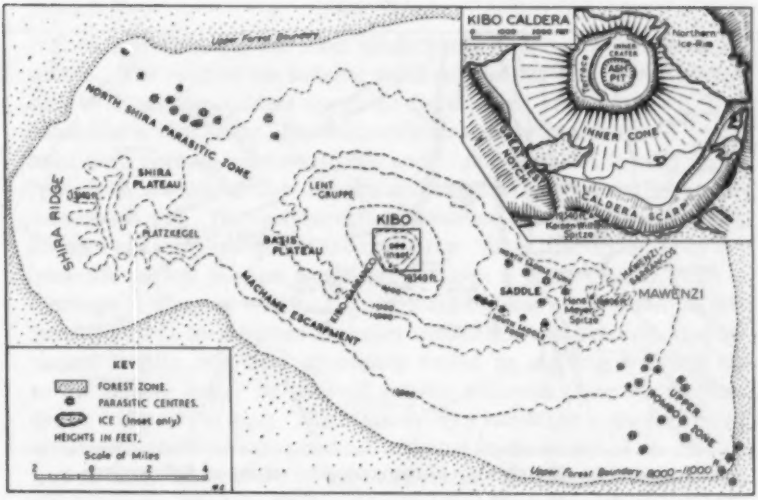
During the summer of 1953 the Geological Department of the University of Sheffield sent a party of four staff-members to the Kilimanjaro massif, Tanganyika, at the invitation of the Geological Survey Department, Dodoma. The expedition was strengthened by three members of the Tanganyika Geological Survey, and approximately sixty man-weeks were spent investigating the geology, glaciology and volcanology of the mountain. This work was carried out mainly above the tropical rain-forest belt, that is, above an average height of 9,500 feet, an area of about 300 square miles. The members of the Expedition were Drs. C. Downie, N. J. Guest, D. W. Humphries, G. P. Leedal, and Messrs. D. N. Sampson, W. H. Wilcockson (Leader), and P. Wilkinson, and this paper is a product of the work of all members. It is a preliminary account of the geological results of this Expedition. The rock names used are field-terms and are only provisional. The detailed results will be embodied in a Memoir of the Geological Survey of Tanganyika.

I. Introduction

(*a*) *Location and Topography*

The volcanic massif of Kilimanjaro lies within Tanganyika, just south of the Kenya Boundary, 3° S. and 37° 20′ E. It is an imposing mountain, spreading, with its foothills, 50 miles in a W.N.W.–E.S.E. direction and 30 miles across. Its mass is impressive for it rises to a general height of 12,000 to 14,000 feet from the even plateau of the Basement Complex, which slopes from 4,000 feet, in the west to 2,500 feet, in the east. Individual summits rise far higher : Kibo, the central cone and highest point in Africa, reaches 19,340 feet ; Mawenzi, in the east, attains 16,896 feet ; while in the west, the Shira Ridge, whose highest point rises only to 13,140 feet, is nevertheless a sizeable mountain (see Text-fig. 1).

Reaching such a height on the equator, it is natural that Kilimanjaro passes through many climatic zones. From the savanna the land rises, through a cultivated zone, by stages to a perpetual snowline. Above the cultivated zone lies a belt, from 5,000 to 10,000 feet, of dense tropical



TEXT-FIG. 1.—Map of localities on Kilimanjaro above the Forest Zone.

rain-forest. Nearly all the Expedition's work was carried out above this forest in the regions of moorland and alpine desert.

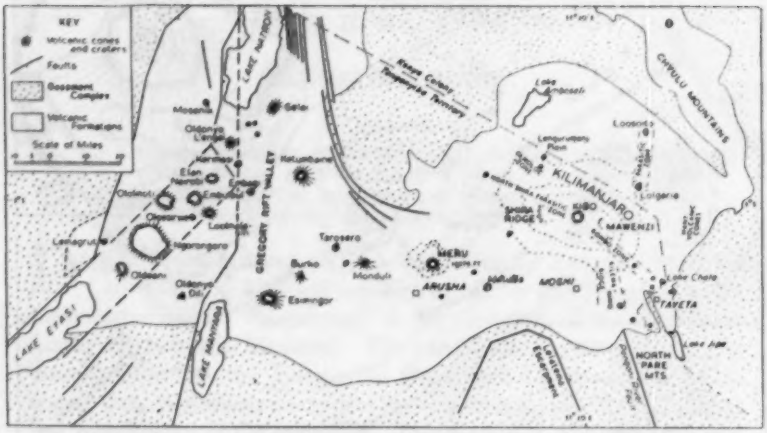
Above the alpine desert the summit of Kibo is partly covered by glaciers, a contrast to which is provided by the solfataric activity in the Inner Crater, at 19,000 feet level.

(*b*) *Regional Geological Setting.*

Kilimanjaro is one of many volcanoes associated with the Rift Valley faulting which poured out great floods of Tertiary and later lavas, from Southern Tanganyika to Ethiopia. Kilimanjaro itself stands more than fifty miles to the east of the Gregory Rift Valley. However it lies near the intersection of several powerful tectonic lines, e.g. the N.N.W.–S.S.E. Basement Complex lines of the Pangani Valley fault and the Lelatema fault escarpment, and the E.N.E.–W.S.W. line of major volcanic cones including Meru (14,955 feet.), Monduli and Esimingor (See Text-fig. 2).

(*c*) *Volcanic Centres*

Kilimanjaro is not a single volcanic cone, but has been built up round three distinct, but complex, centres, identifiable with the main summits mentioned above. The structure is further complicated by a large number of minor parasitic cones.


KEY
Volcanic cones and craters
Faults
Basement Complex
Volcanic Formations
Scale of Miles
LAKE NATRON
GREGORY RIFT VALLEY
Gelai
Kitumbeine
Meru
Oldoinyo Lengai
Kerimasi
Elan Naimbi
Embagai
Oldeani
Ol Doinyo Sambu
Lemagrut
Loolmalasin
Ngorongoro
Olbalbal
Olmoti
Empakaai
Eyasi
Tarosero
Burko
Monduli
Essimingor
LAKE EYASI
LAKE MANYARA
Kwaa Caldera
Lake Jipe
Lake Chala
Taveta
Lake Haw
NORTH PARE MTS
Lossimingori Plain
Lossimingori
Loitokitok
KILIMANJARO
Lolgaria
KIBO
MAWENZI
SHIRA RIDGE
Shira Plateau
Shira Caldera
Shira Cone
Kibo Caldera
Kibo Summit
Kibo Crater
Kibo Glaciers
Mawenzi Glaciers
Mawenzi Crater
Mawenzi Summit
Saddle
Rongai Pass
Rongai Plain
Rongai Crater
Rongai Cone
Rongai Lava Flow
Rongai Tuff Cone
Rongai Tuff Ring
Rongai Tuff Cone
Rongai Tuff Ring
Rongai Tuff Cone
Rongai Tuff Ring

(*a*) *Shira*

Structure.—Shira is the most westerly of the three main centres of activity. The volcano has suffered much erosion and is now represented only by its western caldera scarp, the Shira Ridge, no point of which is much above 13,000 feet. Its structure is essentially that of a cone which must have risen to between 16,000 and 17,000 feet, and is built up of lavas with associated flow breccia and considerable masses of agglomerate and tuff. The reconstruction, however, is made difficult by the absence of more than half of the crater rim. After the formation of the cone the central portion foundered to form a great caldera, with a diameter of about two miles ; the rim did not rise much above 14,000 feet. There is no evidence that this subsidence was accompanied by violent activity, but lava apparently welled up the ring fractures on to the caldera floor. Subsequent activity occurred along the fracture line at one point at least. This is shown by a subsidiary cone formed of an unusual phonolitic lava and tuff, situated on the slopes of the caldera wall at the north west end of the Shira Ridge. The penultimate stage in the development of the Shira centre was the formation of an eccentric inner cone composed largely of doleritic agglomerate injected by dolerite. This cone, now partly eroded, forms the solitary hill rising 800 feet from the caldera floor and is called Platzkegel. Finally dykes were injected, for the most part as a radial swarm. Their thickness is generally from one to two feet and about one hundred were mapped along the four miles of caldera rim that remain. Associated with the dykes and exhibiting complex age relationships with them are several thin sheets intruded with an outward dip into the main mass of lavas.

The Shira centre has been extinct since these hypabyssal bodies were emplaced. Since then considerable erosion has occurred and corrie glaciers have been active on its upper slopes. The east and north walls of the caldera have disappeared under lava flows and fluvioglacial material from Kibo which have spread across the caldera floor to reach the wall in the west.

Succession.—The following succession has been established for Shira centre :

3. Platzkegel Series.
2. Caldera Floor Series.
1. Caldera Rim Series.

The main succession of the caldera rim was measured on the west wall of the caldera where it rises almost 1,000 feet above the floor. Here the following succession was determined :—

(*a*) Upper Shira Trachybasalts and Tuffs.
(*b*) Shira Ultrabasic and Nephelinic Series.
(*c*) Lower Shira Trachybasalts.

The Upper and Lower Trachybasalts are very like the trachybasalts of Mawenzi ; all have abundant platy plagioclase feldspars. Between these two series occur some 400 feet of ultrabasic lavas with olivine and very abundant augite phenocrysts. Some of these also develop large numbers of nepheline phenocrysts, which are sometimes as much as one inch across.

The Caldera Floor Series is mostly covered by lavas from Kibo and by recent sediments, but a remnant was seen east of Platzkegel. This series consists of trachybasalts similar to those of the caldera wall, but was poured out later as flat flows on the caldera floor.

The Platzkegel Series consists of agglomerates and dolerites of the inner core, extruded through and resting on the Caldera Floor Series, as described above.

(*b*) *Kibo*

Kibo is the central and largest of the Kilimanjaro centres. It is a " puy "-shaped volcano rising from Saddle-level (about 14,000 feet) to a height of 19,340 feet at the summit, Kaiser Wilhelm-Spitze. Its circumference at Saddle-level is more than 15 miles, but some of the older lavas from this centre extend much more widely over the lower parts of the mountain. The summit region has subsided to form a spectacular caldera 1½ miles in diameter, with inner walls 600 feet deep on the south side. Within the caldera is the slightly eccentric Inner Cone rising to 19,000 feet and punctured by a crater 900 yards in diameter. Inside the Inner Crater is a third cone, the Ash Cone, with a central crater (the Ash Pit or Reusch Crater) 370 yards in diameter and 425 feet deep. The Inner Crater has a number of solfatari indicating residual volcanic activity. The Caldera also contains the still impressive remains of a former ice-cap, and the flanks of Kibo are coated with extensive but rapidly disappearing glaciers.

Structure.—The dips of the Kibo lavas are gentle and radial but large areas containing evidence of the early history of the volcano have either been buried by ice or covered by the late lavas which form a veneer over a great part of the surface. Indeed little is exposed of the earlier lavas except in the erosional breach of the Great West Notch and Kibo Barranco, so that there is much that is conjectural in the reconstruction of the volcanic history of Kibo. It is believed that, during the extrusion of the Small-Rhomb Porphyry, the Kibo centre lay further to the west than at present, and that cauldron sudsidence also took place at this earlier centre.

Besides central activity, fissure eruption is known to have occurred on the flanks. In particular, many of the phonolite flows probably originated in this fashion.

Other features of the structure of Kibo are the sparse radial dykes of

rock-types related to the lavas, and the Great West Notch Intrusive of feldspathoidal syenite. The latter body is exposed through a thickness of 500 feet, and extends for at least half a mile below the Great West Notch. Its relationship to the surrounding lavas is imperfectly known, but it has a striking system of horizontal joints giving it a stratiform appearance.

TABLE 1.

7. Inner Crater Series
6. Caldera Rim Series
5. Small Rhomb Porphyry
4. Phonolite
3. Rhomb Porphyry
2. Rectangle Porphyry
1. Kibo Trachybasalt

Succession of lavas on Kibo

Succession.—The lavas of Kibo show a consistent order of extrusion, which can most readily be seen in the Kibo-Barranco. The generalised succession is shown on Table I.

The lavas of Kibo are more diverse and show a more complete differentiation than those of the other centres.

The Kibo Trachybasalts (1) are petrographically very similar to the Mawenzi and Shira trachybasalts.

Above the Kibo Trachybasalt the dominant rock-type is rhomb porphyry. This striking rock-type is a coarsely porphyritic lava with a glassy or aphanitic matrix of grey or orange-red colour. The characteristic feature is the abundance of rhomb-sectioned phenocrysts of anorthoclase. There is considerable variation in the size, shape and abundance of these rhomb-feldspars, and the different types can be paralleled in the classic Oslo region. Other and smaller phenocrysts of olivine and augite also occur. In the normal Rhomb Porphyry (3) the edge-length of the rhombs is usually ¾ to 1 inch whereas in the Small-Rhomb Porphyry (5) the edge-length is ½ inch or less. The Caldera Rim Series (6) differs from all the other rhomb porphyries in bearing visible nepheline which forms conspicuous phenocrysts, often attaining a basal diameter of 1 inch or more. The abundance of nepheline phenocrysts is variable, increasing in the later flows. The Rectangle Porphyry (2) is a variety, apparently transitional to the trachy-basalts, in which the feldspars become increasingly tabular in habit and rectangular in cross-section.

The Phonolites (4) are extremely fine-grained lavas the most characteristic feature of which is an almost perfect slate-like fissility.

Finally the Inner Crater Series (7) are unlike any of the other lavas

petrographically, being nephelinites or nepheline phonolites with conspicuous glassy nepheline and pyroxene phenocrysts in a glassy or micro-crystalline matrix.

Distribution.—The oldest member, the Kibo Trachybasalt (1) has been found, so far, only in the Kibo-Barranco and on the Basis Plateau. The base of this series is not seen, and it may be that the whole lower mountain is built up of this lava-type.

The Rectangle Porphyry (2) is found predominantly on the west side of Kibo where it has a wide distribution, stretching as far as the Shira Plateau.

The normal Rhomb Porphyry (3) has an extensive distribution on all parts of Kibo.

The Phonolite Series (4) is very abundant to the S.E. of Kibo and to the N.W. around the Lent-Gruppe, whilst it also occurs sporadically to the W. and S.W. and locally includes important obsidian and obsidian-tuff bands. The Small-Rhomb Porphyry (5) occurs in the Kibo-Barranco and has spilled over extensively on the S.E. side of Kibo, where it is associated with the phonolites.

The Caldera Rim Series (6) is a thick sequence of nepheline rhomb porphyry lavas filling the eroded caldera of the Micro-Rhomb Porphyry (5). In places these characteristic lavas have spilled over the rim and long canal-like flows are found on most of the flanks of Kibo. Subsequent to the outpouring these nepheline rhomb porphyries, cauldron subsidence formed the present day caldera of which the nepheline rhomb porphyries form the rim and summit ridge.

The Inner Crater Series (7) was probably extruded from the ring fracture of the cauldron subsidence, subsequently, from a slightly eccentric eruption centre, forming the Inner Cone. It covered the Caldera floor and spilt over the rim where breaches were available, as at the Great West Notch and over the lower N.E. Caldera rim of Kibo.

Glacial erosion and deposits between several of the above series indicate time breaks of considerable duration. Sediments are intercalated between lavas at several horizons and their importance is shown both by their thickness (150 feet at one locality) and by their widespread development, some of these deposits recurring at the same horizon at localities 2 to 3 miles apart.

(*c*) *Mawenzi*

Mawenzi, rising from the eastern end of the 14,000 feet Saddle, is a striking contrast to Kibo. Its summit, Hans Meyer-Spitze, is 16,896 feet high, nearly 2,500 feet lower than Kibo, consequently there is no permanent ice, and only a few semi-permanent snow-patches. Far smaller in bulk than Kibo, it remains impressive by virtue of the precipi-

tous nature of its highly jagged and intricate rock topography. Moreover the north-east side of the mountain is cleft by two stupendous gorges, called the Ost- and West-Barrancos by Klute, the former being 4,000 feet deep. Movement over the terrain is extremely difficult and, as only a short time was available for investigation, knowledge of the structure remains very imperfect.

Structure.—Mawenzi is the remnant of a highly eroded stratiform volcano of which little, if any, original crater-rim remains. Practically the whole of the east side is missing, probably due to erosion, and not to explosion, as was suggested by Klute. There is a principal eruptive centre around which the dips are essentially centrifugal, but the structure is complicated by subsidiary vents.

Two plugs, the larger with a major diameter of about 300 feet, have been identified under the enormous east face of the mountain. In the neighbourhood of the larger plug there is a considerable development of vent agglomerate with a general centripetal dip.

A prominent feature of the structure of Mawenzi is the suite of dykes, of which there are many hundreds, probably more than a thousand. Usually the dykes are 2 to 3 feet thick, few exceed 6 feet, and many are no more than 1 foot thick. They are, however, often extremely persistent both in lateral extent and in depth. Most dykes are grouped in a swarm running E.S.E.–W.N.W., but there are many others which are radial in disposition.

Succession.—Mawenzi is constructed of trachybasaltic material (trachydolerite of Finckh) intercalated with a few flows of basaltic material. The trachybasalts contain highly characteristic large, platy plagioclase feldspars and have a variety of other phenocrysts and textures. The basalts are invariably fine-grained, compact lavas and usually contain small phenocrysts of olivine and augite.

Klute believed that the material of the upper 3,000 feet of Mawenzi differed from the lavas of the lower parts of the mountain in being mainly pyroclastic in origin. Field work in 1953 suggested that these " brockentuffen " of Klute are, in fact, dominantly flow-brecciated trachybasaltic lavas whose structure is a result of the flow of gassy lava by the " aa-mechanism ". These " lava-breccias " are nevertheless accompanied by subordinate quantities of solid lava and true agglomerate and tuffs. Resting on this series, and partly intercalated with the higher members, is a group of massive trachybasaltic and basaltic lavas which has, however, been eroded down to about the 14,000 feet level.

The 4,000 feet of trachybasaltic " lava-breccias " exposed in the Barranco sections suggest that much of the lower concealed portion of the volcano is constructed of this material.

Intrusion of the dyke-swarm is the last phase of activity on Mawenzi.

The rock-types are trachybasalts and olivine basalts resembling closely the diverse varieties of Mawenzi lavas.

(*d*) *The Parasitic Cones*

The flanks of Kilimanjaro are obscured in places by lavas poured out from numerous small parasitic cones. This is particularly so to the south-east where the lavas and tuffs from these cones extend on to the plains composed of Pre-Cambrian rock, reaching as far as Lake Chala and Taveta, and in the north-west where they reach down to the Lengurumani Plain. These small centres are distributed in well defined zones suggesting fracture-belts. The zones examined in some detail were the Upper and Lower Rombo Zone to the south-east of Mawenzi, the Saddle Zone between Kibo and Mawenzi and the North Shira Zone north-west of Kibo. Within the forest and on the surrounding plains there are probably hundreds of these cones, few of which could be visited. Mostly they are located in broad but well-defined zones, the main ones being the Lower Rombo Zone, the Himo-Kilema Ridge, the Lolgaria-Loosoito, North Shira and Ol Moloc Zones.

Most of these parasitic cones are well preserved often with a well-defined crater. On the Saddle, however, their form has been considerably altered by glacial action and in some instances spectacular crag and tail features have resulted. The cones are all small, few, if any, exceeding a height of 350 feet above the surrounding country. On the other hand the lava erupted from them was often extensive and late flows from parasitic vents obscure the underlying geology over large areas. This is especially so on the south side of the Saddle and on the south-east flanks of Mawenzi.

Various rock types occur in the parasitic cones but the most common are olivine basalts and ultrabasic rocks with prominent olivine and augite phenocrysts. On the Saddle most of the cones consist mainly of cinder but the final phase was usually the collapse of the crateral area and the outpouring of basaltic lava. In the Upper Rombo Zone the cones were mostly built of lava, and pyroclastics were subsidiary except in the later stages. Foundering of the crater has occurred in some cases. The North Shira, Lower Rombo and Himo-Kilema Ridge Zones are known to have cones built up of lava and pyroclastics.

III. The Age of Kilimanjaro

(*a*) *Age relationships between the centres*

Members of earlier expeditions have expressed opinions concerning the age relationships of the volcanic centres of Kilimanjaro, basing their conclusions mainly on the different states of erosion of the cones.

The present expedition, on the basis of geological field relations, has been able to establish the age relationships more certainly.

At several localities the normal Rhomb Porphyry (3) of Kibo rests on various levels of the Mawenzi trachybasalt and basalt. It is quite clear that all the later activity of Kibo including the formation of the main part of the cone is wholly later than the Mawenzi activity. Similarly the normal Rhomb Porphyries (3) and Rectangle Porphyries (2) of Kibo rest on the eroded cone and caldera of Shira, flooding into the breached caldera. Thus the main part of the Kibo cone was formed after activity at Shira had entirely ceased.

The relationship of the trachybasalts, which are the oldest exposed rocks of Kibo, to the lavas of Mawenzi and Shira has not, however, been directly determined. It is unlikely that any contact between these rocks is exposed, in the upper part of the mountain at any rate. There is nothing to indicate that the trachybasalts from all three centres were not being extruded at much the same time and, in view of their great similarity to each other and their contrast with the later lavas of Kibo and the parasitic cones, it seems reasonable to infer that they were more or less contemporaneous.

The parasitic cones are among the younger volcanic manifestations of the mountain and, being developed along tectonic lines, are probably roughly contemporaneous. The Saddle Zones give a more precise indication of age. All the centres are older than the last main glaciation and one was found to rest on the Small-Rhomb Porphyry (5) of Kibo which rather closely limits the period of their possible activity. Moreover, one at least of these cones includes flows of nepheline rhomb porphyry identical to those of the Caldera Rim Series (6) of Kibo and it may well be that the parasitic cones are contemporaneous with the outpouring of this series from Kibo.

(*b*) *The Geological Age*

No direct evidence of the geological age of any part of the mountain has yet been discovered, though intercalcations of volcanic rocks with fossiliferous horizons in the extensive lacustrine deposits on the plains around Kilimanjaro may eventually come to light as in the case of the adjacent Meru. Meanwhile deductions based on the relations between volcanic outpourings and glacial erosion and deposition may give valuable indications of the age of the mountain. It seems certain that in spite of the continued fumarolic activity, very little can have been extruded since the Pleistocene. All the lavas of Kibo succeeding the trachybasalts and all the parasitic cones are apparently of Pleistocene age having glacial deposits interbedded at several localities. Only the Inner Crater Series (7) may be Holocene. The trachybasalts of Kibo, Mawenzi and Shira and the earlier unexposed rocks of the

mountain may either be Pleistocene or earlier but the absence of any intercalcated glacial sediment in these lavas makes a pre-Pleistocene age seem more probable.

IV. Acknowledgments

Grateful acknowledgment is made to the following : the Geological Survey of Tanganyika, especially to its Director, Mr. C. B. Bisset, who made the Expedition possible ; to the University of Sheffield for encouragement and financial assistance ; to the Colonial Office for providing a grant of Colonial Development and Welfare funds from the Central Allocation for Geological Surveys ; to Dr. Dixey, Director of Colonial Geological Surveys, and Professor L. R. Moore for encouragement and reading the manuscript, and to Professor R. M. Shackleton, who also read and criticized the manuscript, to Mr. M. Cutler, of the University of Sheffield Geography Department, for redrawing the maps, and finally to Dr. N. J. Guest for the interpretation of the rift faulting in the western half of Text-fig. 2.

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EXPLANATION OF PLATES VII AND VIII

Oblique aerial photographs, published by kind permission of the Department of lands and Surveys, Dar-es-Salaam, Tanganyika Territory.

Plate VII.—Mawenzi and Kibo from the east.

Mawenzi, centre foreground, with Kibo, right, six miles away across the Saddle. Meru is seen left, 55 miles distant.

Prominent features of Mawenzi are : East Face, 5,500 feet high, dropping towards the Mawenzi Barrancos, below photograph ; the main plug (ringed) ; the dense dyke-swarm.

On Kibo are seen the 500 feet Caldera Scarp, to the left, and the Inner Cone rising from the Caldera.

Plate VIII.—Kibo from N.W.

Mawenzi is seen at extreme left.

Prominent features of Kibo are : Kaiser Wilhelm-Spitze, 19,340 feet, in middle of rim of Caldera Scarp, top-right, and, below, the cliffs of the Breschenwand, which dominates the Kibo-Barranco ; the Northern Ice-Rim, left, the Credner Glacier, centre, the Drygalski Glacier and two branches of the Penck Glacier, right ; the Lent-Gruppe, bottom right.

MAWENZI AND KIBO FROM THE EAST.

KIBO FROM NORTH-WEST.

On *Heliolites caespitosa* Salter

By V. S. Colter

Abstract

Heliolites caespitosa Salter (1873) is shown to be identical with *Heliolites parvistella* Roemer (1861) var. *intricata* Lindström (1899). The varietal name must, therefore, become *caespitosa*. Evidence is brought forward to suggest that the two varieties of this coral are the results of differing environments.

ONE of the commonest, but not always most conspicuous, of the corals in the Wenlock Limestone reefs of Shropshire is a dendroid form, which was at first identified as *Heliolites caespitosa* Salter (1873). Examination of thin sections, however, showed that the internal structure of the coral differed from that of *Heliolites caespitosa* as described by F. R. C. Reed (1902), but was identical with that of *Heliolites parvistella* Roemer (1861), the dendroid habit indicating the variety *intricata* of Lindström (1889).

Concerning the structure of *H. caespitosa*, Reed wrote :—" Larger corallites small, very numerous, approximate, usually less than half their diameter apart, in some cases contiguous ; margin slightly exsert, but calyx sunk below general surface ; walls crenulated and infolded to form 12 short septa, extending in from one-quarter to one-third the diameter of the calyx. Smaller corallites (coenenchyma) not numerous, usually only 2–4 irregular rows between the larger corallites ; polygonal in shape, with well developed walls and regular horizontal, and mostly equidistant tabulae, so as to divide the tubes into a series of square cells."

The Wenlock specimens under examination differ from this description only as regards their septa, which, far from being short, extend into the centre of the calyx, and there give rise to a reticulate mesh exactly as in *H. parvistella*. Lindström wrote of this species :—

" Septa long, meeting in the centre of the calicle, where they intercross, and form a more or less complicated reticulation.

Tabulae irregular, as it were, broken up between the loculi and curved upwards or convex."

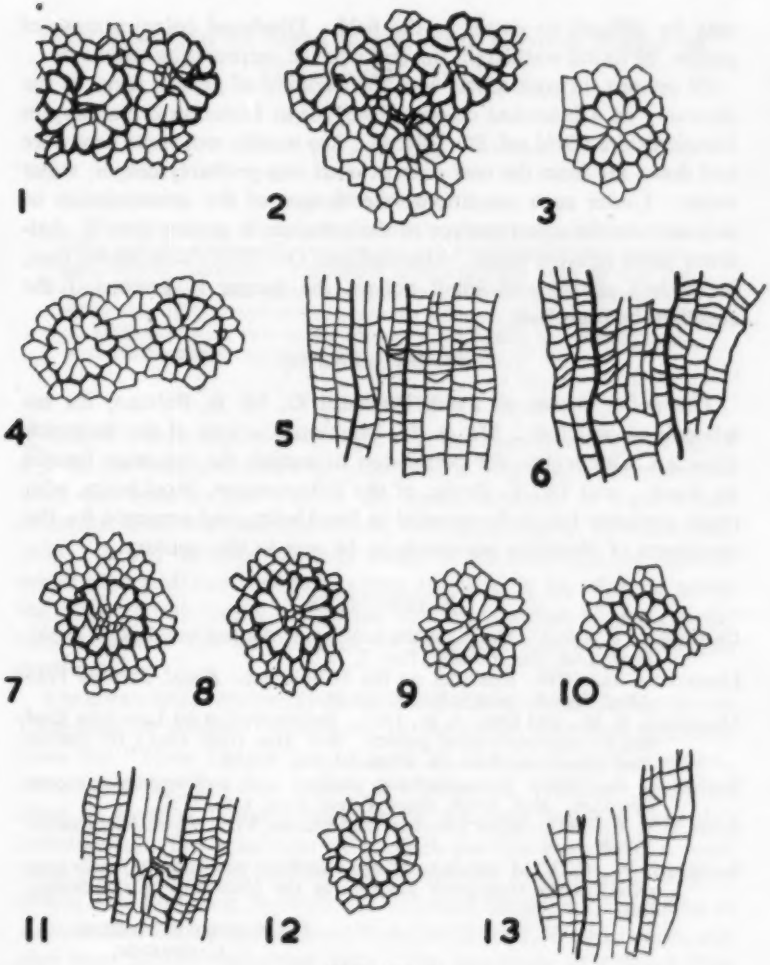
This breaking up of the tabulae and the filling of the calices by reticulate tissue often make it difficult to distinguish the calices from the surrounding coenenchyma.

The original specimens of *H. caespitosa* were examined, and from the exterior it could be seen that the septa do, in fact, meet in the centre of the calyx, but that the reticulation is often obscured by the matrix, which fills many of the calices. Subsequently, thin sections were cut and the true structure of this coral revealed. (Text-fig. 1, 1 and 2.)

A comparison of these slides and those of other Wenlock material (Text-fig. 1, 12 & 13), with Lindström's figures, and with some of his original slides, loaned by the Naturhistoriska Riksmuseum, Stockholm, (Text-fig. 1, 3–7) shows the presence, to a greater or lesser degree in all corallites, of a reticulation produced by the intergrowth of the septa. Since the only structural difference between *H. parvistella* and Reed's description of *H. caespitosa* lay in the nature of the septation, which is now shown to be identical, *Heliolites caespitosa* Salter (1873) must be considered synonymous with the growth form of *Heliolites parvistella* Roemer (1861) that has been called var. *intricata* by Lindström (1899). Salter's name *caespitosa* has priority over Lindström's varietal name *intricata*, and the branching form must therefore be named *Heliolites parvistella* Roemer var. *caespitosa* Salter. There is evidence to suggest that the two growth forms, laminar and branching, of this coral are not true varieties, but it seems useful to retain the varietal name to distinguish the branching form. The lectotype chosen is the specimen figured by Reed (1902, fig. 6) which is in the Sedgwick Museum, Cambridge (A.4124).

In addition to the obviously dendroid specimens, there occur, in the Wenlock Limestone, thick laminar forms, in which the branching is absent, or reduced to a few elevated knobs on the surface of the corallum. These specimens have the same internal structure (Text-fig. 1, 9, 10 & 11) and growth form, as the laminar variety of *H. parvistella*, and must be considered to belong to this species. Whilst the dendroid forms occur commonly in, and frequently characterize, the centre of the reefs, the laminar colonies have been found growing on the sediments immediately surrounding them. It is suggested, therefore, that the two varieties of this coral are merely ecological variants, and that the shelter of the reefs permitted the development of branched forms, whilst branching was inhibited by the stronger bottom currents round the reef margin. Another factor which may have been effective in producing changes in the form of the corallum, is sand-scour. Crossland (1928) has shown that in Tahiti the normally branching or palmate *Millepora* forms simple incrustations where exposed to the effects of water-borne sand. The results of sand-scour could be expected to be more pronounced in corals growing round the edges of the Silurian reefs, and on the smooth surface of the surrounding sediments, where currents bearing fine calcareous sand would meet little to hinder their progress. Other, normally domed, tabulate corals tend to adopt a flatter growth form in this region of the reef. Payne (1942) notes this effect in certain North American reefs, and attributes it to the smothering effect of sediment swept off the reef.

This zoning is probably not absolutely rigid, but the branching types seem only to have grown in the centres of the reefs, where they



TEXT-FIG. 1.

1.—T.S. of two corallites of *Heliolites caespitosa* from Dudley (Reed 1902, pl. xvi, figs. 6 & 7). Specimen now lectotype of *Heliolites parvistella* var. *caespitosa*. (Sedg. Mus. A.4124e.)
2.—T.S. of three more corallites of lectotype. (Sedg. Mus. A.4124d.)
3 & 4.—T.S. of corallites of *Heliolites parvistella* from Ekstа, Gotland. (Original, unnumbered slide in Riksm., Stockholm.)
5.—V.S. of above.
6.—V.S. of one corallite of *Heliolites parvistella* from Lau, Gotland. (Original, unnumbered slide in Riksm., Stockholm.)
7 & 8.—T.S. of two corallites of *Heliolites parvistella* from Stora Karlsö. (Original, unnumbered slide in Riksm., Stockholm.)
9 & 10.—T.S. two corallites of *Heliolites parvistella* from Ridge Co.'s Qy., Much Wenlock, Shropshire. (Sedg. Mus. A.45735d.)
11.—V.S. of above. (Sedg. Mus. A.45735c.)
12.—T.S. of corallite of *Heliolites parvistella* var. *caespitosa* from the Lilleshall Co.'s Qy., Presthope, Much Wenlock. (Sedg. Mus. A.45734e.)
13.—V.S. of above.

(All figs. × 10.)

may be difficult to detect in the field. Displaced colonies may, of course, be found washed off the reef into the surrounding sediments.

Of interest, in connection with the question of growth form, is the discovery of a branched colony (A.45738) at Limebrook Nunnery in Herefordshire (Grid ref. SO 374658). The muddy sediments here were laid down far from the reef zone in what was probably deeper, stiller water. Under such conditions, the danger of the accumulation of sediment on the upper surface of the corallum is greater than in shallower more agitated water. Marshall and Orr (1931) have shown that, in modern corals with small polyps, the danger is lessened if the corallum be branched.

Acknowledgments

The writer wishes to thank Professor O. M. B. Bulman, for his advice and criticism ; Mr. A. G. Brighton, Curator of the Sedgwick Museum, Cambridge, for permission to section the specimen figured by Reed ; and Dr. T. Ørvig, of the Riksmuseum, Stockholm, who made available for study material in Stockholm, and arranged for the specimens of *Heliolites parvistella* to be sent to this country.

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The Insertion of Septa in the later Growth Stages of Clisiophyllid Corals

By G. R. Coope

(PLATE IX)

Abstract

The major septa of clisiophyllid corals originate deep down in the calyx and grow upwards, fanning out towards both the axis and the periphery of the coral. The minor septa originate high up near the rim of the calyx and appear in pairs one septum being inserted on either side of each new major septum. The insertion of minor septa on both sides of a new major septum complicates the development of the subsequent major septum at the fossula.

Introduction

SINCE Kunth in 1869 discovered that the insertion of major septa in the Rugose Corals took place only in four sectors, considerable work has been carried out on the septal insertion in these corals (Duerden, 1902 and 1906, Carruthers, 1906, Schindewolf, 1931, Hudson, 1936). It was however the early stages of the coral and the primary septal plan that received the greatest attention in an effort to relate the rugose corals to the hexacorals, and the insertion of septa in the later stages in the development of the coral has been somewhat neglected.

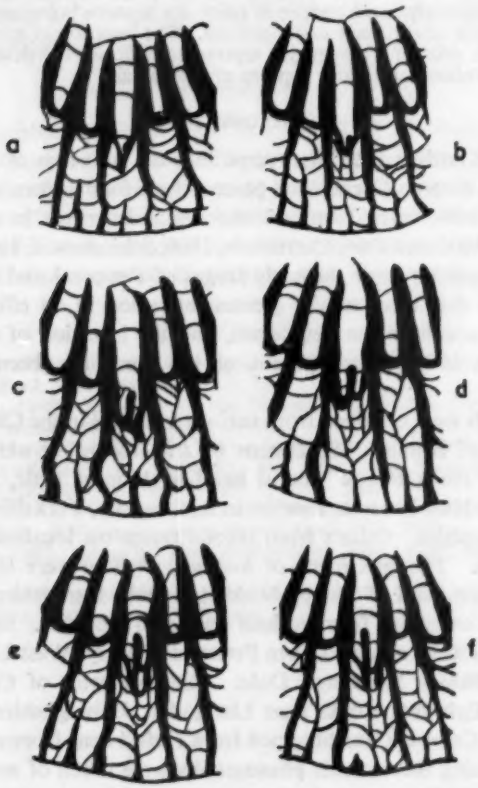
The corals were obtained from various localities in the Carboniferous Limestone of Britain. Specimens of *Dibunophyllum* were examined from the "Hobs House" coral band in Monsal Dale, Derbyshire, from above Hull Pot near Horton in Ribblesdale, Yorkshire, and from Bieth in Ayrshire. Others from several unknown localities were also investigated. The specimens of *Koninckophyllum* were from a coral band near the head of Stoney Middleton Dale, Derbyshire, and again others were examined from various unknown localities. Specimens of *Aulophyllum* were obtained from Petershill Quarry, West Lothian, and also from Stoney Middleton Dale. The specimens of *Clisiophyllum* were from Eglwyseg Rocks near Llangollen, Denbighshire. A single example of *Corwenia* was obtained from Hafod near Corwen.

In examining these corals photographs were taken of serial parallel surfaces ground transversely across the coral at measured intervals which were usually less than 1 mm. In this way it is possible to follow the development of individual septa within the fossulae. The structural details of the young septa were investigated from thin slices cut at various stages in their develpoment. The growth of the septa in the alar fossula was most easily followed since the more abundant secretion of fibrous calcite in the cardinal fossula tended to obscure the earliest stages of septal development.

I wish to thank Dr. S. H. Straw for his assistance during the course of this work and also Professor F. W. Cope and Dr. I. Strachan for their helpful criticism and suggestions during the preparation of this paper.

The Development of Septa in Dibunophyllum and Koninckophyllum

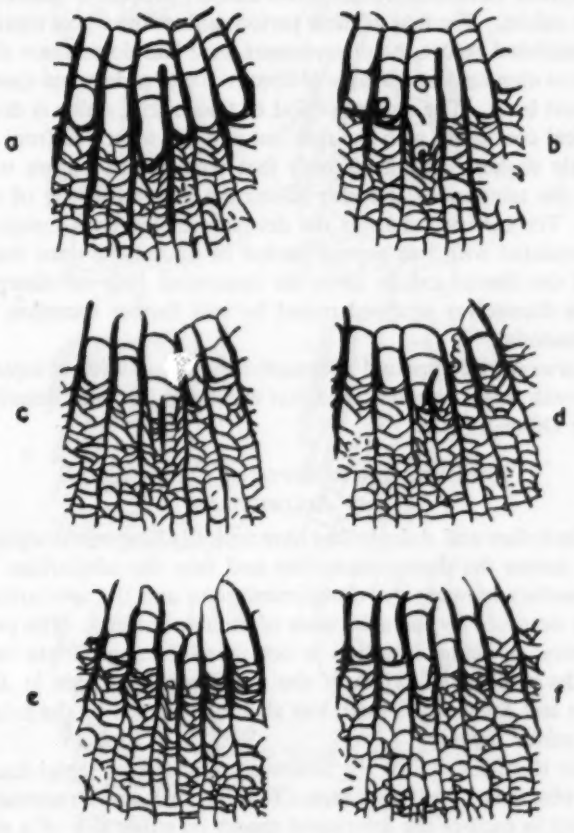
In their later growth stages *Dibunophyllum* and *Koninckophyllun.*



Text-fig. 1.—A series of surfaces ground at 0·5 mm. interval across the alar fossula of *Dibunophyllum bipartitum* (McCoy) from above Hull Pot, near Horton in Ribblesdale. BU 682, × 4.

have wide dissepimentaria. In *Dibunophyllum* the minor septa are short and degenerate (Hill, 1939, p. 65) but in *Koninckophyllum* they are considerably longer. In both these corals however the minor septa do not extend, typically, as far as the boundary between the dissepi-

mentarium and the tabularium. It is near this boundary that new major septa are added to the coral. These septa first appear in the fossulae in the form of small buds upon the innermost ring of dissepiments (Text-figs 1b, 2b) and develop both axially and peripherally. The outward growing edges of these septa thus approach the inner edges of minor septa which had been formed previously in the same interseptal spaces.



TEXT-FIG. 2.—A series of surfaces ground at 1 mm. interval across the alar fossula of *Koninckophyllum magnificum* (Thompson and Nicholson), from near the head of Stoney Middleton Dale, Derbyshire. BU 683, × 4.

With further growth of the major septa, they meet and fuse with these minor septa and from this stage onwards the development is as of single major septa extending from the periphery inwards towards the axis of the coral. Shortly after this fusion, minor septa appear at the

periphery of the coral, one on each side of the recently formed major septum (Text-figs. 1f and 2f). In their earliest growth stages the minor septa sometimes appeared to arise from the point where the young major septum was in contact with the periphery of the coral.

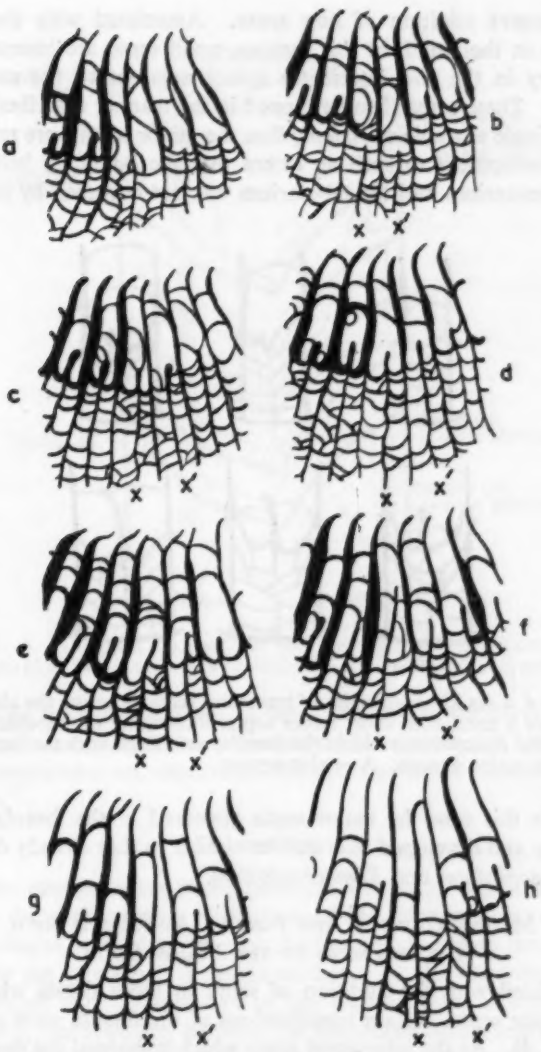
The details of structure of the young major septa in *Dibunophyllum* are illustrated by the representative slice shown on Plate IX. The major septa appear to have undergone two distinct periods of thickening by fibrous calcite. The first of these periods affects the whole septum and was completed before the dissepiments were laid down since they can be seen to abut against the layer of fibrous calcite and are not themselves thickened by it. The second period of thickening, which is deposited in optical continuity with the first but is often separated from it by a distinctly darker line, affects only that part of the septum which is within the tabularium and also affects the innermost ring of dissepiments. The earliest stages in the development of young major septa are associated with this second period of thickening since they abut against the fibrous calcite upon the innermost ring of dissepiments and are themselves wrapped round by still further secretion of the same material.

In *Corwenia*, a compound *Dibunophyllum*, the addition of septa in the late growth stages was similar to that which has just been described for solitary Dibunophylla.

The Insertion of Septa in Clisiophyllum and Aulophyllum

Clisiophyllum and *Aulophyllum* have typically long minor septa which extend across the dissepimentarium and into the tabularium. Thus the boundary between the dissepimentarium and the tabularium was already occupied by the axial ends of the minor septa. The previous description of septal insertion is not therefore appropriate here because the position of origin of the major septa, as seen in *Dibunophyllum* and *Koninckophyllum*, was already occupied by the axial ends of the minor septa.

Under these conditions the following sequence of septal insertions can be observed. Two small septa (Text-fig. 3b, x and x′) appear at the periphery in each of the interseptal spaces on either side of a recently formed major septum. These septa appear almost simultaneously and in their earliest developmental stages they occasionally arose from the peripheral end of the newly formed major septum. These septa then grew until they had attained the length of the minor septa. At this stage the septum on the counter side (x′) of the new major septum ceased to grow and remained a minor septum throughout the remaining length of the coral. The septum on the cardinal side (x) however, that is the septum whose axial end lay in the fossula, paused

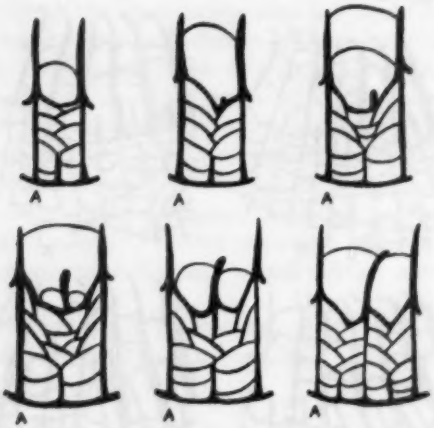


TEXT-FIG. 3.—A series of surfaces ground at 2 mm. interval across the alar fossula of *Aulophyllum fungites* (Fleming), from Petershill Quarry. BU 684, × 4.

in its development and for a while was indistinguishable from the minor septa. After this pause it grew rapidly until it had attained the length of the major septa. The duration of the pause in development became longer as the coral approached a cylindrical form with the consequent

less frequent addition of new septa. Associated with the sudden increase in the length of this septum, small septa are inserted at the periphery in the two interseptal spaces adjacent to the new major septum. These septa then developed in the manner described above.

In a single example of *Aulophyllum* the minor septa were retarded in their development to such an extent that the boundary between the dissepimentarium and the tabularium was not occupied by their axial

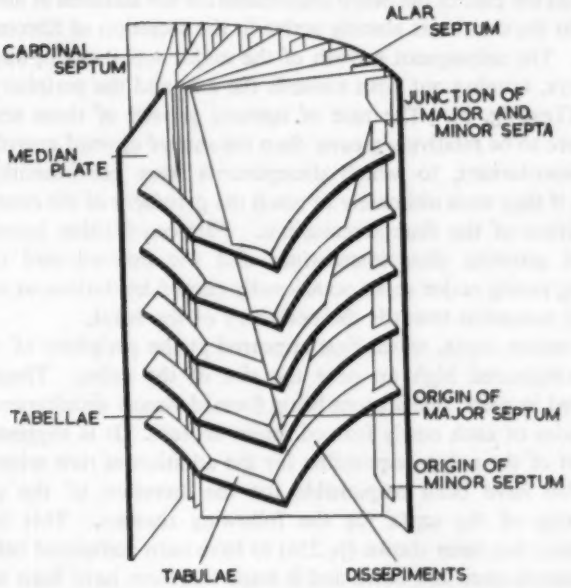


TEXT-FIG. 4.—An idealized series of transverse sections across the alar fossula of a coral with short minor septa, illustrating the modifications of the dissepiments within the fossula, associated with the incoming of a major septum. A = alar septum.

ends. In this case the major septa appeared in the fossula at this boundary and developed in a manner similar to that already described for *Dibunophyllum* and *Koninckophyllum*.

MODIFICATIONS OF THE FOSSULA ASSOCIATED WITH THE INCOMING OF THE MAJOR SEPTA

Associated with the addition of septa in those corals which had short minor septa, certain modifications of the fossula were observed (Text-fig. 4). As the interseptal space which contained the developing major septum grew wider, the overlap of the inosculating dissepiments became less and less until eventually they became separated in the centre of the space. The gap so formed was filled by smaller dissepiments. The dissepiments along the margins of the fossula thus became inclined at a very low angle to the two adjacent adult major septa. With still further widening of the fossula the small dissepiments in the centre of the interseptal space, may themselves inosculate. The subsequent



TEXT-FIG. 5.—Diagram to illustrate the insertion and development of the septa at an alar fossula in a clisiophyllid coral with short minor septa.

growth of the peripheral end of the young major septum divided this pattern of dissepiments down the centre of the interseptal space so that the dissepiments on either side showed the usual " herring bone " pattern.

INTERPRETATION

In the interpretation from transverse sections of septal insertion in corals, the configuration of the base of the calyx must be considered since several successive calicular floors—and therefore time planes—may be cut through in a single section. As the dissepiments slope downwards and inwards and as the tabulae slope downwards and outwards, the boundary between the dissepimentarium and tabularium is the deepest part of the calyx and the rim of the calyx is represented by the periphery of the section (Text-fig. 5).

The major septa, therefore, which first appeared in the fossulae at the boundary between the dissepimentarium and the tabularium, originated in the deepest part of the calyx. From the distribution of the secondary thickening, which is best developed at this boundary, it is evident that this also was secreted by that part of the polyp which occupied the deepest part of the calyx. It is therefore interesting to

note that the part of the polyp responsible for the addition of new major septa to the coral was already active in the secretion of fibrous calcite tissue. The subsequent growth of the major septa was upwards into the calyx, fanning out both towards the axis and the periphery of the coral (Text-fig. 5). The rate of upward growth of these septa had therefore to be relatively greater than the rate of upward growth of the dissepimentarium, to which dissepiments were continuously being added, if they were ultimately to reach the periphery of the coral across the surface of the dissepimentarium. This competition between the upward growing dissepimentarium and the upward and outward growing young major septa occasionally caused hesitations or setbacks in their extension towards the periphery of the coral.

The minor septa, which first appeared at the periphery of the sections, originated high up near the rim of the calyx. These septa appeared in pairs, one septum being formed almost simultaneously on both sides of each newly formed major septum. It is suggested that the part of the polyp responsible for the addition of new minor septa may also have been responsible for the secretion of the primary thickening of the septa for the following reasons. This layer of thickening has been shown (p. 236) to have been completed before the dissepiments were laid down and it must therefore have been secreted high up in the folds in which the crests of the major septa were formed. Since the minor septa sometimes appear to arise from the junction of the newly formed septum with the periphery of the coral and since they originated high up near the rim of the calyx, the part of the polyp responsible for the insertion of these septa must have been very close to the fold in which the crest of the new major septum was being formed. That part of the polyp therefore responsible for the secretion of the primary thickening on the new major septum could not have been far removed from the origin of the two associated minor septa.

The addition of minor septa on both sides of a recently formed major complicated the development of subsequent major septa at the fossula since a minor septum thus occupied the peripheral part of the interseptal space in which the next major septum was due to be inserted. If the minor septa were short, then the outward growing edge of the young major septum met and fused with the inner edge of the minor septum that was occupying the same interseptal space (Text-fig. 4) (cf. *Dibunophyllum* and *Koninckophyllum*). If, on the other hand, the minor septa were so long that they extended across the dissepimentarium and into the tabularium then an axial edge of a minor septum already occupied the position of origin of the major septum. Under these conditions the major septum grew directly upon the axial edge of the minor septum with little or no discontinuity (cf. *Aulophyllum* and *Clisiophyllum*).

DIBUNOPHYLLUM BIPARTITUM.

Thus the insertion of additional septa during the later growth stages of clisiophyllid corals was basically similar in all the specimens investigated though individual peculiarities and differences of structure in the various genera considered, modified the method of septal insertion and the subsequent development of the septa within the calyx.

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EXPLANATION OF PLATE IX

Transverse section of a cardinal fossula in *Dibunophyllum bipartitum* (McCoy), from above Hull Pot, near Horton in Ribblesdale, showing a young major septum at the boundary between the tabularium and the dissepimentarium of the left of the cardinal septum (C). BU 681, × 20.

Conodont Horizons in the West and South-West of England

By D. L. Dineley and F. H. T. Rhodes

Abstract

A large number of Devonian and Carboniferous limestones from the West and South-West of England have been sampled for conodont faunas. Only 15 yielded conodonts, but the faunas show striking similarities to those of America and Germany. The presence of "Ordovician" forms in these assemblages is noted and an explanation offered.

Introduction

THE existence of rich British Lower Palaeozoic conodent faunas prompted the present search for conodonts in the Upper Palaeozoic strata of the West and South-West of England. The area offers a wide selection of fossiliferous limestones in the Devonian and includes the Avonian type section, and it was suspected that these might yield valuable conodont material. Sixty samples from these rocks were collected for examination and a brief outline of the results is given below.

Devonian conodonts in this country were first recorded from limestone near Newton Abbot by Young (1880), but no further investigation of these fossils followed. Carboniferous conodonts are recorded from Scotland (Smith 1900, 1907 ; Craig, 1954), the north Midlands and Pennine areas (Edwards and Stubblefield, 1947 ; Stubblefield and Calver *in* Stevenson and Mitchell, 1955), and South Wales (Ramsbottom, 1952). A rich conodont fauna has been found by the present writers in the Edale Shales (Namurian) near Castleton, Derbyshire. Conodonts have been used in North America to correlate and date several Devonian and Mississippian formations (see especially Ellison, 1946 ; Hass, 1947) and they may prove to be of similar value in the western counties of England. A systematic investigation of the conodont faunas from the classic Devonian and Carboniferous localities of Europe has not yet been made, though Sannemann (1953) offers a tentative subdivision of the Upper Devonian of the Frankenwald into conodont zones. Sannemann (1953, 1955, 1955a), Matern (1933) and Beckman (1949, 1953), have described Upper Devonian conodonts from the Rhineland, while Eichenberg (1930), Mater (1933), and Schmidt (1934) have described Carboniferous species. Gross (1955) has recently re-examined conodont histology, and other conodont studies are in progress in Germany. Their importance to workers in Britain is likely to be considerable.

It is hoped to publish at a later date detailed accounts of the conodont faunas obtained during the present investigation.

Localities and Method of Investigation

In the collection of samples from South Devon the writers have relied upon the statigraphical determinations of Anniss (1933), Lloyd (1933), and Ussher (1913). Hambling's map (1910) of North Devon has been used to locate small lenticular limestones in the Ilfracombe and Pilton Beds. The latter beds have received special attention, for Mr. R. Goldring has recently demonstrated (1955) that the Pilton Beds are divisible into a lower (Strunian) part and middle and upper (Tournaisian) parts. Twelve Devonian samples were collected from North Devon, 21 from South Devon : 5 Lower Carboniferous samples were collected from North Devon, 4 from Westleigh (Owen, 1939), 18 from the Bristol Avon Gorge and Mendip Hills. Reynolds' (1921) account of the exposures studied by Vaughan in the Bristol Gorge has been used as a guide there.

Samples of about 2 lbs. weight from each limestone horizon (dolomites were not sampled) have been digested and the residues sorted in the manner previously described (Rhodes, 1953). Digestion by acetic acid is usually a very slow process : formic acid may be used to obtain quicker results without apparent detrimental effect to the conodonts. It is, however, considerably more expensive.

Results

A. *Horizons yielding conodonts*

Of the 60 rock samples examined only 15 were productive and it is apparent that the conodont faunas are most unevenly distributed. Dark, somewhat crystalline, shelly or crinoidal limestones appear to be the most frequent rocks to yield conodonts, though prolific faunas were obtained from the pale limestones of Lower Dunscombe, Ransleigh and Old Woods in South Devon. Only two of the many thin crinoidal limestones in the Lower Pilton Beds were productive. These are faintly bituminous blue bands, up to but usually less than 1 ft. thick, and appear to be segregations of drifted shelly or crinoidal debris. The upper part of the massive Lower Frasnian Limestone at Lower Dunscombe similarly consists very largely of shelly or crinoidal debris and includes a considerable brachiopod fauna. Lower horizons within the Lower Frasnián limestone have, with the exception of the sample from Holman's Wood, proved unproductive.

In the Carboniferous, conodonts have been obtained from the shelly and thin limestones interbedded with shales of the K and Z zones (Lower Limestone Shale Group of Kellaway and Welch, 1955), and also from the massive grey, shelly and crinoidal limestones of the " Fish Bed " and Horizon γ (in the Black Rock Limestone of Kellaway and Welch, 1955).

B. *Remarks upon the conodont faunas*

The following descriptions are in approximately stratigraphical order : Ordnance Survey grid references for the localities are included.

Locality 1.—?Upper Givetian. Old Woods pit, Torquay (20/904658). Grey thin-bedded limestone below lilac-blue shales in mid part of southern face of pit.

This horizon yields a prolific, well-preserved conodont fauna. Hindeodellids, bladed forms such as *Ozarkodina*, polygnathid and palmatolepid types are the most common. A wide range of denticulated bar types is present and several typical Upper Devonian genera are well represented, for example *Ancyrodella*, *Hibbardella*, *Icriodus* and *Synprioniodina*.

Locality 2.—Lower Frasnian. Holman's Wood, near Chudleigh. (20/879809). Massive, calcite-veined limestone at base of upper level, south-east corner, old quarry.

Only 12 conodonts were obtained but they are exceptionally well-preserved and include several almost perfect very large specimens of *Hindeodella* and small forms of *Gnathodus* and *Polygnathus*.

Localities 3 *and* 4.—Lower Frasnian. Lower Dunscombe Farm, Chudleigh (20/885791). Massive crystalline limestone (3) with fragmentary fossils at foot of western face of old orchard quarry ; massive, shelly and crystalline limestone (4) 10 ft. above previous sample.

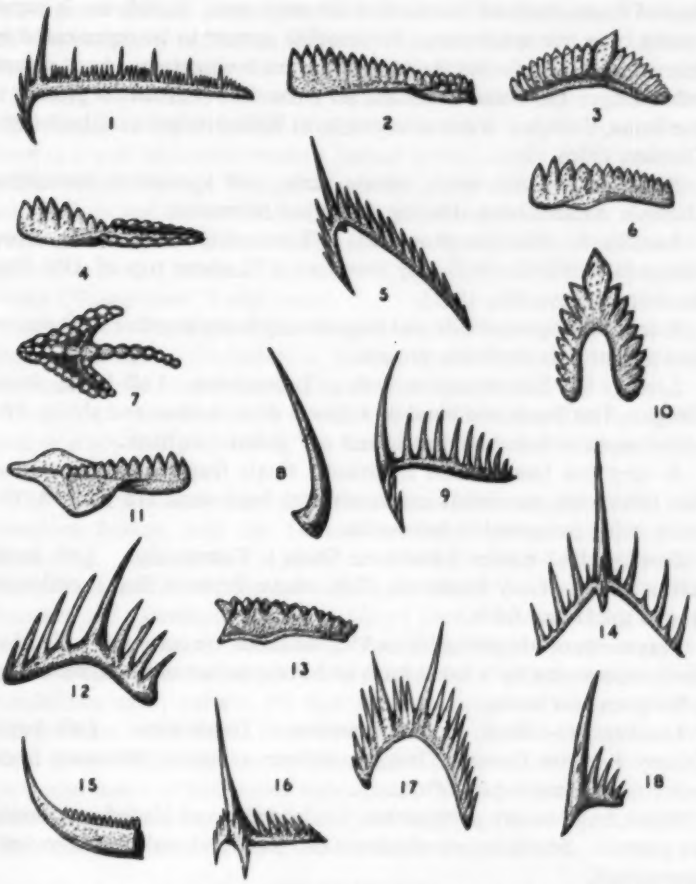
Both horizons yield a very abundant and generally well-preserved fauna, though the higher horizon (4) is the more productive. *Polygnathus*, palmatolepids and bladed forms including the Upper Devonian *Bryantodus* are common. The typically Upper Devonian genera *Ancyrodella* and *Icriodus* are well represented while *Elsonella*, *Falcodus* and *Synrioniodina* also occur. Hindeodellid fragments, ligonodinids and prioniodids are numerous. The lower Palaeozoic forms, *Belodus*, *Oistodus* and *Paltodus*, are represented by a few large individuals.

Locality 5.—Lower Frasnian. Ransleigh (Ransley) Quarry, East Ogwell (20/844702). Pale limestone band near foot of centre of quarry face.

A well-preserved and varied conodont fauna is present, containing typical Upper Devonian genera. *Palmatolepis* is by far the most abundant genus, but *Ancyrognathus* and *Ancyrodella* are also common. The genera *Polygnathus* and *Bryantodus* are present and *Roundya* occurs, but is rare.

Localities 6 *and* 7.—L. Pilton Beds : Strunian. Saunton, North Devon (21/445388). Blue crystalline and crinoidal bands of limestone in blue-grey shale, (6) 45 ft. north and (7) 3 ft. south of old pipeline on foreshore immediately below Saunton Sands Hotel.

The faunas are reasonably well preserved but many of the platformed conodonts show signs of abrasion or fracture. The initial



TEXT-FIGS. 1–18.—Conodont genera from the Upper Devonian limestones of Devonshire. All figures × 30, except figure 8 which is × 35.

1. *Hindeodella*, 2 *Gnathodus*, 3 *Ozarkodina*, 4 *Polygnathus*, 5 *Synprioniodina*, 6 *Spathognathodus*, 7 *Ancyrodella*, 8 *Drepanodus*, 9 *Ligonodina*, 10 *Elsonella*, 11 *Palmatolepis*, 12 *Lonchodina*, 13 *Icriodus*, 14 *Hibbardella*, 15 *Belodus*, 16 *Roundya*, 17 *Falcodus*, 18 *Prioniodus*.

samples yielded abundant conodonts and fish remains (about 100 specimens or large fragments) ; later samples were much less productive. About 15 conodont genera have so far been identified and two new genera may also be present. Large polygnathids are the most conspicuous members ; *Gnathodus* and *Spathognathodus* are also common. A large number of hindeodellid fragments are present, but

bladed forms such as *Ozarkodina* are very rare. *Lonchodus* is represented by a few specimens. Prioniodids appear to be represented by numerous fragments but their identification is uncertain. As at several other Upper Devonian localities, an Ordovician element is present in the fauna, though it is not as strong as at Bishopsteignton (Rhodes and Dineley, 1956).

Small conical fish teeth, ornate scales and specimens resembling Harley's Astacoderma (Harley, 1861) are numerous.

Locality 8.—Shirehampton Beds : Tournaisian. Left bank, Avon Gorge (31/559752). Buff grey limestone 7 ft. above top of Old Red Sandstone (Reynolds, 1921).

A few poor ligonodinids and fragmentary fangs together with one or two minute fish teeth are present.

Locality 9.—Shirehampton Beds : Tournaisian. Left bank, Avon Gorge. Top limestone band in a group of limestone and shales 3 ft. below massive limestone just inland of " point " in bank.

A very few hindeodellid fragments, single fragmentary fangs and fish teeth with numerous ostracods and bryozoans are present, the latter being preserved in haematite.

Locality 10.—Lower Limestone Shale : Tournaisian. Left bank Avon Gorge. Grey limestone 12 ft. above Bryozoa Bed ; collected from a thickness of 6 ft.

Fragments of hindeodellids and ligonodinids are common ; *Gnathodus* is represented by a small form and *Polygnathus* and *Ozarkodina* by a few poor specimens.

Locality 11.—Black Rock Limestone : Tournaisian. Left bank Quarry 1, Avon Gorge. Grey, crystalline, crinoidal limestone from lower face of main part of quarry.

Small, fragmentary polygnathid, hindeodellid and bladed conodonts are present. Several types of minute fish teeth and scales are also well represented.

Locality 12.—Black Rock Limestone (Fish Bed) : Tournaisian. Black Rock Quarry, Avon Gorge (31/562746). Dark bituminous crinoidal limestone.

A small number of well preserved hindeodellids, prioniodids, fish scales and teeth occur.

Locality 13.—Black Rock Limestone (Horizon γ) : Tournaisian. Black Rock Quarry, Avon Gorge.

This horizon yields an abundant fauna including a wide variety of conodonts, fish teeth and scales. The conodonts are very well preserved, being mostly hindeodellids, polygnathids and ligonodinids. Many isolated fangs are present ; some are undoubtedly single cones, others fragments of complex types. *Trichonodella, Lonchodus, Prioniodella* and *Ozarkodina* are represented by several forms. The Ordo-

vician genus *Belodus* is represented by a very robust species. The fish remains include a variety of delicately ornamented scales and minute plates ; many are similar to those from the Lower Pilton Beds.

Locality 14.—?Black Rock Limestone : Tournaisian. Windsor Hill, Somerset (31/618452). Buff, argillaceous, coralliferous limestone at top of old north-western face of quarry south of trackway.

The conodonts are few, small and fragmentary, hindeodellids, polygnathids and forms of *Lonchodus* being the most notable. *Belodus* is also present. The fish scales are large and numerous, being mostly flat and smooth : conical fish teeth and minute, spherical, amber-like bodies ("? egg-cases ") also occur.

Locality 15.—? Black Rock Limestone : Tournaisian. Waterlip Quarry, Somerset. (31/661452.) Grey, crinoidal limestone at foot of southern side of cutting leading from flooded quarry.

Conodonts are rare and poorly preserved, being fragments of hindeodellids and prioniodids for the most part. A few conical fish teeth are also present.

The present search has unfortunately yielded comparatively few conodont faunas, and the Tournaisian has been particularly disappointing. Apart from the presence of " Ordovician " species within them, these British faunas are strikingly similar to those of North America and Germany where the Upper Devonian conodont ranges have been or are being ascertained. To account for the presence of the Lower Palaeozoic forms within the Upper Palaeozoic faunas two possibilities exist, namely (1) that the stratigraphical ranges of the " Ordovician " conodonts must be extended or (2) that Ordovician or other Lower Palaeozoic rocks contributed detritus and fossils to the Devonian and Carboniferous sediments. The latter seems to be the preferable alternative, and was adopted by Branson and Mehl (1940) when dealing with a similar problem in the United States.

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The Lower Carboniferous Outliers of the Colvend and Rerrick Shores, Kirkcudbrightshire

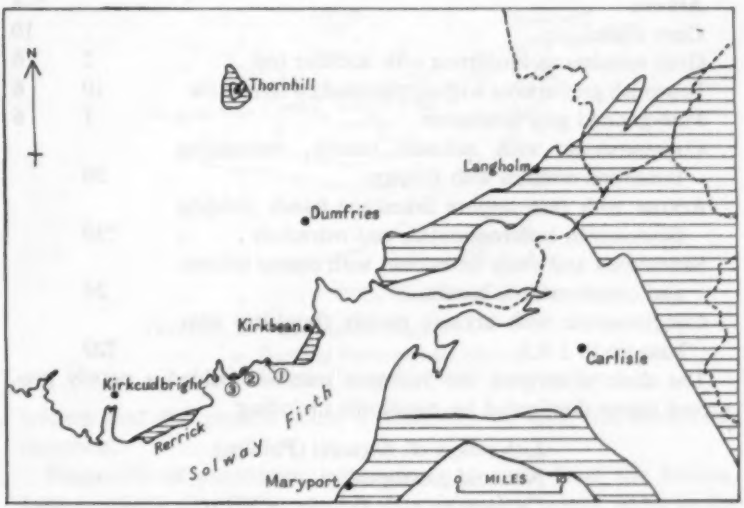
By G. Y. Craig and A. E. M. Nairn

Abstract

The rocks are coarse-grained deposits of Cementstone and Fell Sandstone age. The succession in the Rerrick outlier consists of the Wall Hill sandstones (900 ft.) unconformable on Silurian, followed by the Orroland Limestone Beds (80 ft. +) yielding fossils indicative of Cambeck age. The succeeding coarse red Barlocco conglomerate (210 ft. +) is capped by the Rascarrel beds, some 1,200 ft. of felspathic sandstones and arkoses, with coarse conglomerates. The rocks of the three outliers to the east are of Barlocco-Rascarrel facies. All four outliers are downfaulted against Silurian and have a regional dip to the south-east.

Introduction

FIVE small outliers of Lower Carboniferous rocks flank the N.W. shore of the Solway Firth. Brief accounts of these rocks are to be found in the Geological Survey Explanation of Sheet 5 (1896), the Regional Handbook for the South of Scotland (1935, 2nd edition 1948) and Smith (1910). Revision of the Kirkbean outlier has recently been completed (Craig, 1956) and the present paper is concerned with the description of the four remaining outliers lying to the south-west (see Text-fig. 1).



Text-fig. 1.—Distribution of Carboniferous rocks (shaded) in S. Scotland and N.W. England.
1. Southwick Merse. 2. Portling-Portowarren.
3. Gutcher's Isle-Castlehill Point.

Colvend Outliers

(*a*) *Southwick Merse* (Text-fig. 1 (1))

Patches of a conglomerate with an arkosic matrix (80+ ft. thick) crop out for a distance of some 300 yards east of the merse-trapped stack known as Lot's Wife. The lithology is similar to that of the Portling-Portowarren outlier.

(*b*) *Portling-Portowarren* (Text-fig. 1 (2) ; Text-fig. 2a)

The outlier forms a strip about half a mile in length, downfaulted against Silurian. The rocks are mostly arkoses with conglomeratic bands (boulders up to 2 ft.) almost entirely derived from adjacent porphyrite intrusions (described by King, 1936) in the Silurian, together with occasional greywacke and shale fragments. Shales and thin sandy limestones with infrequent algal fragments are interbedded. The succession totalling 155+ ft. is :—

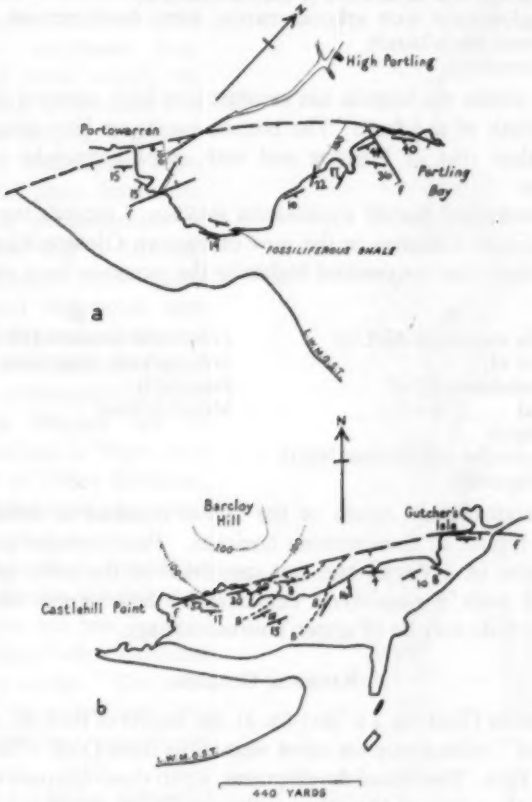
	ft.	*in.*
Arkose with some thin nodular fine-grained limestones	12+	
Grey shale with felspathic material, fossiliferous (see below and Text-fig. 2a)	1	
Brownish grey limestone		8
Grey shale	1	
Arkose		5–8
Grey shales		10
Grey arenaceous limestone with nodular top	2	6
Brownish grey arkose with ripple-marked sandstone	10	6
Fine-grained grey limestone	1	6
Conglomerate with arkosic matrix, containing limestone nodules with felspars	50	
Arkose with thin impure limestone bands yielding *Bevocastria*, bellerophontids and ostracods	?30	
Sandstones and shaly limestones with coarse arkosic and conglomeratic bands	24	
Conglomerate with arkosic matrix (boulders near base up to 2 ft.)	?20	

The shale underlying the youngest member yielded a poorly preserved fauna dominated by nautiloids including

Lithophaga cf. *lingualis* (Phillips)
Naticoid gastropod
Cycloceras
Loxoceras?
Spirorbis
Fish remains

(*c*) *Gutcher's Isle—Castlehill Point* (Text-fig. 1 (3) ; Text-fig. 2b)

The Carboniferous/Silurian unconformity is impressively exposed at the eastern end of the outlier, which is some two-thirds of a mile in extent. In the present cliffs a veneer of carbonate-cemented Lower Carboniferous breccia clings to sheer cliffs of Silurian rock and it is



TEXT-FIG. 2.—Geological maps of :—
a. Portling-Portowarren outlier.
b. Gutcher's Isle-Castlehill Point outlier.

evident that the present coast is following an early Carboniferous shoreline.

Fragments of porphyrite, greywacke, and shale form the breccia. Low southerly dips (22°), possibly depositional in origin, occur in the matrix. Breccia-filled fissures in Silurian rocks between Gutcher's Isle and Portowarren are interpreted as vein and fault breccias of pre-Carboniferous age.

The succession is :—

	ft.
Black shale	?
Arkose and brownish yellow sandstone	10
Brownish yellow sandstone (Fossil horizon A)	
Arkose and brownish yellow sandstone	20–30
Grey calcareous sandstone (Fossil horizon B)	
Conglomerate with arkosic matrix, some finer grained carbonaceous bands	30 +
Basal breccia	

Faulting within the breccia has resulted in a high seaward dip immediately south of the fault. The breccia passes up into conglomerate coarser than that of Portling and with more greywacke and shale fragments.

The Geological Survey *Explanation to Sheet* 5 records the presence of *Syringopora ramulosa* in the now overgrown Glenstocking quarry. Two horizons (see succession) higher in the sequence have yielded :

A	B
Modiola megaloba McCoy	*Leiopteria lunulata* (Phillips)
Myalina cf. *redesdalensis* Hind	*Schizophoria resupinata* (Martin)
Pectinid	*Fenestella*
Bucaniopsis	Murchisoniid
Punctospirifer scabricosta North	
Rhynchonellid	

The unsatisfactory nature of the faunal evidence is unfortunately only too typical of Cementstone horizons. *Punctospirifer scabricosta* is suggestive of a Visean age, but specimens of the same species are associated with *Syringothyris cuspidata* at Southerness (Kirkbean) where the beds may be of upper Tournaisian age.

Rerrick Outlier

This outlier (Text-fig. 1 ; Text-fig. 3), the largest of the four, extends a distance of 7 miles along the coast westwards from Door of the Heugh to White Port. The inland development, up to three-quarters of a mile, is greater than that of the other outliers. The succession established is :—

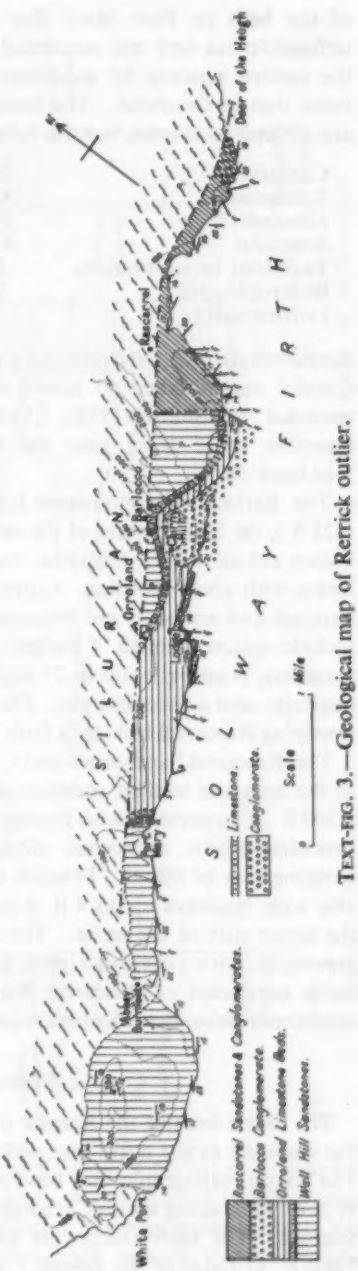
	ft.
Rascarrel Sandstones and Conglomerates	1,200–1,300
Barlocco Conglomerate	210 +
Orroland Limestone Beds	80
Wall Hill Sandstones	*circa* 900

The Wall Hill Sandstones are exposed from White Port eastwards to Port Mary. The sandstones are massive, coarse-grained, frequently current-bedded and occasionally ripple-marked. A characteristic is the development of spherical, ovoid, or irregularly banded, iron-

enriched masses which transect ordinary sedimentary structures and are of secondary origin. The masses may reach a diameter of 3 ft. and show concentric banding.

Conglomeratic bands yield abundant sandstone fragments of local origin, together with greywacke, felsitic and granitic material. Rare grey shales yield indeterminable plant fragments. The basal conglomerate of White Port Bay is followed by fine-grained purple sandstones and red marls with thin discontinuous bands and nodules of cementstone type. The unconformable junction with the Silurian can be closely defined in White Port Bay and at Abbey Burnfoot, while inland it can be traced as a feature.

The Orroland Limestone Beds, variable in thickness and facies, are best exposed on the shore below Orroland Shooting Lodge. The basal part of the succession contains rudaceous greyish red limestones with highly fossiliferous lenses, separated by coarse pebbly sandstones. These basal beds totalling some 17 ft. are followed by about 60 ft. of reddish brown and grey sandstone with pebbly bands (cobbles up to 5 inches), which in turn grade into red sandy marls and shales bearing limey nodules. At the westernmost exposure



TEXT-FIG. 3.—Geological map of Rerrick outlier.

of the beds in Port Mary Bay the basal limestones appear to be unfossiliferous and are succeeded by conglomerates (represented in the eastern outcrop by sandstones), the total thickness being about twice that at Orroland. The fossils in the limestones are detrital and are difficult to extract, but the following forms were obtained :—

Caniniids
Syringopora
Edmondia ?
Schizodus
Taxodont lamellibranchs
Bellerophontid
Loxonematid
Naticoid gastropod
Orthoceratids
Nautiloids
Camarotoechia pleurodon (Phillips)
Dictyoclostus teres (Muir Wood)
Syringothyris cuspidata? North

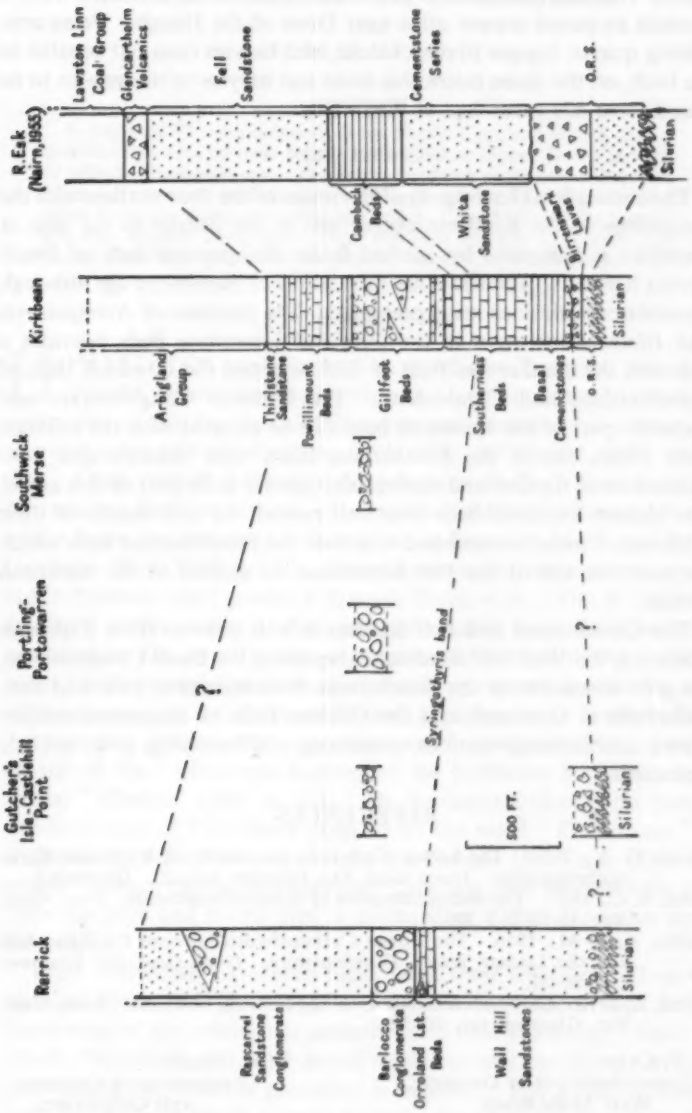
Syringothyris and *Dictyoclostus teres* are indicative of Cambeck age. Careful search failed to reveal any specimens of *Lithostrotion* [?] recorded by Smith (1910). Lithologically the limestones closely resemble those lying near the base of the Gillfoot Beds in the Kirkbean outlier.

The Barlocco Conglomerate forms the main mass of Cairny Hill (425 ft.), the highest point of the outlier. The conglomerate is a reddish brown colour with a felspathic matrix and includes reddish siltstone lenses with green mottling. Current-bedding is common in the sandy partings and washouts are frequent. Contained cobbles and boulders include quartz (up to 4 inches), purple brown sandstone (up to 8 inches), porphyrite (up to 23 inches) and less commonly greywacke, quartzite, and a chocolate grit. The conglomerate is separated from the overlying Rascarrel beds by a fault of unknown throw.

The Rascarrel Sandstones and Conglomerates lie in the eastern part of the area and in their southern development consist of some 1,200–1,300 ft. of a coarse pinkish brown arkose with some pebble bands and chocolate-brown micaceous siltstones. In the softer bands green mottling may be found. Towards the north-east, however, conglomerates with boulders up to 4 ft. 6 in. in size replace the sandstones of the upper part of the series. The contained boulders are dominantly greywacke with occasional pink granite and porphyrite. Some 200 yards north-east of Rascarrel Burn mouth, carbonaceous felspathic sandstones have yielded plant fragments and a productid.

Structure

The oldest beds of the Rerrick outlier appear in the south-west and the youngest in the north-east with the regional dip to the south-east. The coastal topography has been influenced by the powerful E.N.E.–W.S.W. fault along which Carboniferous has been downthrown against Silurian. The fault reaches its maximum observed throw of about 2,000 ft. at Door of the Heugh ; at White Port it is absent, while to



TEXT-FIG. 4.—Comparative sections of the Carboniferous rocks of S. Scotland.

the north-east it appears to die out in Southwick Merse, no trace of it having been found in the Kirkbean area. Mineralization has developed along the fault plane and in the adjacent Carboniferous rocks of the Rerrick outlier. Barytes was worked until recently in a mine near

Cairny Hill and malachite is at present (1955) being extracted from a recently reopened copper mine near Door of the Heugh. Veins containing quartz, copper pyrites, calcite, and barytes crop out parallel to the fault, on the shore below this mine and barytes veins are also to be found some 400 yards east of Port Mary.

Correlation

The correlation (Text-fig. 4) of the rocks of the four outliers with the successions in the Kirkbean outlier and in the district to the east of Dumfries is hampered by marked facies changes and lack of fossiliferous horizons. The strata are mostly of Fell Sandstone age although Cementstone horizons are represented. The presence of *Syringothyris* and *Dictyoclostus teres* in the Orroland Limestone Beds provides a link with the Southerness Beds of Kirkbean and the Cambeck Beds of Dumfriesshire and Cumberland. The Barlocco Conglomerate and probably part of the Rascarrel beds can be equated with the Gillfoot Beds which overlie the Southerness Beds. The arkoses and conglomerates of the Colvend outliers also appear to be part of this series. The highest Rascarrel beds may well extend—by sole reason of their thickness, it must be confessed—up into the Powillimount Beds which are near the top of the Fell Sandstone, as defined in the Kirkbean outlier.

The Cementstone and Fell Sandstone beds coarsen from Kirkbean westward, the Wall Hill Sandstones replacing the Basal Cementstones, the grey limestones of the Southerness Beds becoming pink and conglomeratic at Orroland, and the Gillfoot Beds of calcareous reddish brown cobble conglomerates coarsening and becoming more arkosic westwards.

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Devonian Goniatites from North Cornwall

By M. R. House

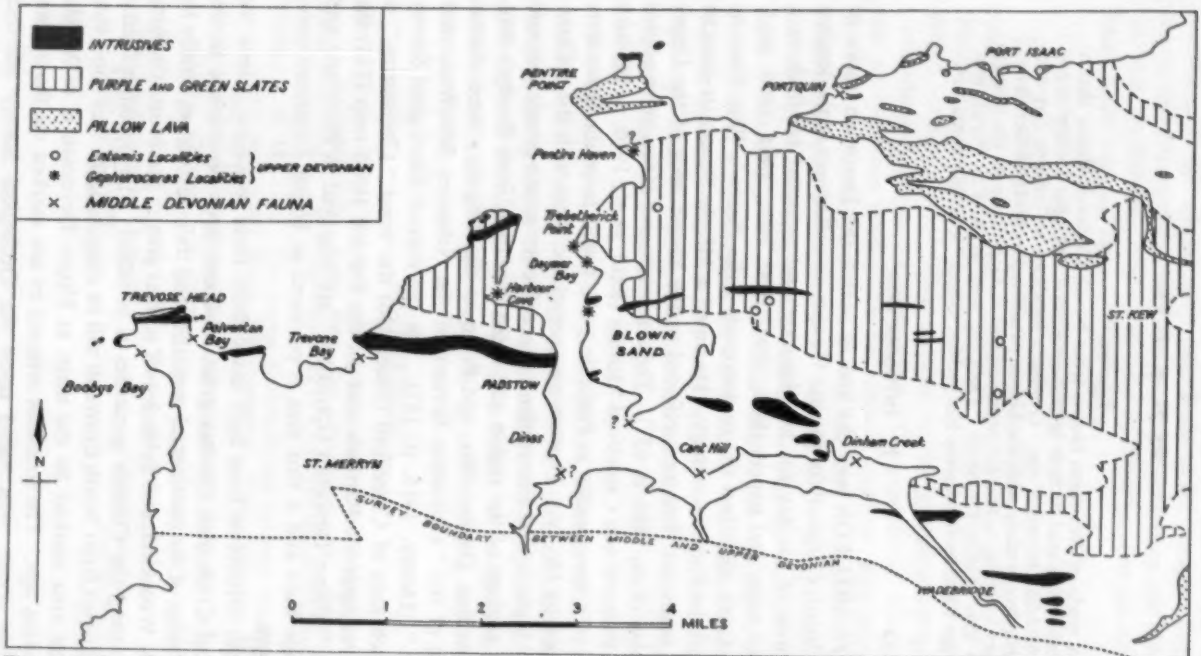
Abstract

A study of Devonian faunas from North Cornwall shows that a considerable area of beds hitherto regarded as Upper Devonian are of Middle Devonian age. Goniatite localities at Trevone Bay and Portquin correlate with the Upper Maenioceras Stufe of Germany: other localities within the area mapped as Grey Slate by the Survey are also Middle Devonian. Only the area marked as Purple and Green Slate by the Survey has yielded Upper Devonian goniatites.

1. Introduction

HOWARD FOX was the first to search the Devonian rocks of North Cornwall for fossils. He sent his collections to the leading authorities of his day for identification and recorded his finds in a series of notes and papers (Fox, 1894, 1900, 1901, 1904, 1905, etc.). G. C. Crick identified the cephalopods from Booby's Bay, Trevone Bay and the Padstow estuary. He noted a Middle Devonian element in the fauna yet they were referred to the lowest beds of the Upper Devonian (Fox, 1894, p. 637). These records and others were copied in the Padstow and Camelford Memoir (Reid, *et al.*, 1910, p. 26) with details of a new locality at Portquin : the fossils from the latter were identified by Dr. Ivor Thomas who correlated them with the " Chiloceras " Stufe (lowest Famennian). Later Dewey gave a general account of the geology of the region and listed goniatites from Booby's Bay, Trevone Bay, Daymer Bay, and Portquin claiming they were characteristic of the " Chiloceras horizon of the Nehdener Schichten, near Brilon " (Dewey, 1914, p. 157). On the current Geological Survey one-inch map of Camelford (Sheet 336) the word " Cheiloceras " is engraved opposite Portquin and on the Trevose Head map (335) the words " Upper Devonian Goniatites " are engraved in Polventon and Trevone Bays and a vast area is coloured as Upper Devonian upon the maps.

Fresh collections have been made from these localities. Since the time of Crick and Thomas great advances have been made in the knowledge of the continental goniatites and their succession, chiefly by Frech, Wedekind, and Schindewolf so that greater precision in naming and dating the Cornish goniatites is possible. The goniatite faunas now known from North Cornwall will be described, for they show that a large area marked on the maps as Upper Devonian is of Middle Devonian age. The localities referred to are marked on the accompanying sketch map based upon the Geological Survey one-inch maps (Text-fig. 1).



TEXT-FIG. 1.—Geological sketch-map of the Padstow region showing the localities referred to in the text (based on the Geological Survey one-inch maps).

2. Middle Devonian Localities

All the localities which have provided Middle Devonian faunas lie within the area mapped as Grey Slate by the Survey.

(1) Trevone Bay. The small, well-preserved, pyritized fossils from Pentonwarra Point, Trevone were discovered by Fox who described the locality (1894, p. 637). The goniatites found were listed by him, with identifications by Crick, in 1901 (p. 541 et seq.) and were copied in the Padstow Memoir (p. 20). The list includes : *Bactrites budesheimensis*, *B.* sp., *Tornoceras simplex*, *T.* sp., *Anarcestes* cf. *latiseptatus*, *A.* sp., *Mimoceras compressum*, *M.* sp., and *Agoniatites transitorius* ?. The new collections contain *Agoniatites* aff. *costulatus* (d'Arch. & de Vern.), ? *Holzapfeloceras circumflexiferum* (G. & F. Sandb.), *Maenioceras* sp. juv., ? *Sobolewia* sp., *Wedekindella* spp. *Tornoceras* (*T.*) *simplex* auct., *Arkonoceras* sp., and *Michelinoceras* sp.

Crick's list as it stands shows clear Middle Devonian affinities. Only *B. budesheimensis* and " *T.*" *globosum* are known exclusively from the Upper Devonian. The fossils identified with the former are considered to belong to the genus *Arkonoceras* Flower (1945, p. 701) for the siphuncle lies half way between the centre of the shell and the wall and no ventral lobes are formed. *Arkonoceras* was erected on a form from the Middle Devonian of Ontario. The true *Goniatites globosus* M nster is a *Cheiloceras*. The involute forms with constrictions from Trevone (and Portquin) cannot belong to *Cheiloceras* for they have markedly biconvex growth lines. Since similar forms from Portquin possess a median dorsal saddle they are referred to the Upper Middle Devonian genus *Wedekindella*. The genotype of *Wedekindella*, *W. brilonensis* (Kays.), has growth lines and constrictions similar to the forms under discussion. It has not yet been possible to trace the pattern of suture development which Schindewolf (1933, p. 101) has suggested is similar to *Holzapfeloceras*.

(2) Portquin. The locality here was described in the Padstow Memoir (p. 26) and several goniatites were noted from a band in the grey slate below the Pillow Lavas. The goniatites from here are in all respects identical with those at Trevone. New collections include : *Agoniatites* aff. *costulatus* (d'Arch. & de Vern.), *Maenioceras terebratum* (G. & F. Sandb.), *Wedekindella* spp., *Tornoceras* (*T.*) *simplex* auct., *T.* sp., *Arkonoceras* sp., *Michelinoceras* spp., and in addition the Geological Survey collections contain *Maenioceras* aff. *terebratum* (G. & F. Sandb.) (Geol. Surv. No. 1570 CR). As at Trevone the rotund, involute forms are referred to *Wedekindella*.

All the goniatites on the new lists are consistent with a Middle Devonian age for the beds at Trevone and Portquin. *Agoniatites* is unknown in the Upper Devonian. *Wedekindella* and *Maenioceras* are Upper Middle Devonian forms (Schindewolf 1933, p. 88). *Sobolewia* is

also an Upper Middle Devonian goniatite (Wedekind 1918, p. 155). The fauna therefore correlates best with the Upper Maenioceras Stufe or the " Maeneceras " terebratum zone of Schmidt (1926, p. 295).

(3) Booby's Bay. The fossiliferous locality discovered by Fox in Booby's Bay was well described in the Padstow Memoir (p. 18). The only goniatite recorded was '*Goniatites* (*Anarcestes*) *noeggerathi* (v. Buch). The suture line of *Latanarcestes noeggerati* is not similar to that of any Upper Devonian goniatite and it is considered, bearing in mind the general reliability of Crick's other identifications, that the rocks here are also Middle Devonian.

(4) Polventon Bay. In the Sedgwick Museum is a single goniatite collected by C. G. Lamb from Polventon Bay (SM, H 5214a) that is identical with the specimens from Trevone tentatively referred to the Middle Devonian *Holzapfeloceras circumflexiferum* (G. & F. Sandb.).

(5) Cant Hill. In 1905 Crick described several cephalopods from Cant Hill collected by Fox and identified *Agoniatites* sp., *Orthoceras* cf. *commutatum* Gieb., *Cophinoceras* sp., and *Phragmoceras* (?). Also, from a locality east of Cant Cove, *Orthoceras* cf. *hercynicum* Kays. His conclusion was that these beds must be " certainly Devonian and most probably Eifelian or lower Middle Devonian age ". (Crick, 1905, p. 160). *Agoniatites* is only known from the Lower and Middle Devonian.

(6) Dinham Creek. From a locality east of Dinham Creek, discovered by Fox, Crick identified *Orthoceras longicameratum* Foord and *O. rapaeforme* Roem. towards *O. subconicum* Roem. As Crick noted these forms were described from the Wissenbach Slate of Middle Devonian age.

(7) At several localities within the grey slates of the southern part of the Padstow estuary the Survey record fossils more characteristic of the Middle than the Upper Devonian (Padstow Memoir, pp. 22–24). It is clear from the text that the surveyors strongly suspected they were mapping Middle Devonian beds but they referred them to the Upper Devonian, supposing the beds at Booby's Bay and Trevone to be of that age.

All the localities noted above lie within the area mapped as Grey Slate and marked as Upper Devonian, yet all have yielded a typical Middle Devonian fauna. No unquestionable Upper Devonian fossils are known from this outcrop. The Survey considered that the Grey Slate was older than the Purple and Green Slate. This has been confirmed by the new goniatite collections : Upper Devonian goniatites have only been discovered within the outcrop of the Purple and Green Slates.

3. Upper Devonian Localities

(1) Daymer Bay. Disturbed Purple and Green Slates crop out on the north side of Daymer Bay. A band on the foreshore was found to contain badly preserved goniatites. Of the forty specimens obtained capable of generic identification all belong to the typical Frasnian genus *Gephuroceras* [*Manticoceras*].

(2) Other Goniatite Localities. Mr. Alan Pedder kindly allows me to record that he has found *Gephuroceras* at several places within the area mapped as Purple and Green Slate. He found *Gephuroceras* at Trebetherick Point ; at about 400 feet south of the minverite intrusion forming the southern point of Daymer Bay ; and also at Harbour Cove. A goniatite from Pentire Haven was tentatively referred to *Cheiloceras*. Dr. Ramsbottom made these identifications.

(3) At several places within the outcrop of Purple and Green Slate Fox discovered ostracods which were sent to Kayser for identification. Kayser concluded that " not the slightest doubt can remain as to the Upper Devonian age, or to the fact that the fossils belong to the Cypridinenschiefer. They might easily have come from the Dillenburg, so close is their geological resemblance to those of the Upper Devonian Rhine " (Fox, 1905, p. 134). Fox's localities are marked on the accompanying map.

4. Stratigraphy and Correlation

The structure of this part of Cornwall is very incompletely understood and little is known of the stratigraphy. A tentative succession was given in the Padstow Memoir (p. 34). The evidence at present available enables the following sequence of dated beds to be made : rocks of uncertain age in the district are not included.

FAMENNIAN ? } FRASNIAN }	Beds of the Purple and Green Slate outcrop. with " *Entomis* " and *Gephuroceras*. ? Pillow Lavas.
GIVETIAN	Black calcareous slate of Trevone and Portquin (Maenioceras Stufe).
EIFELIAN ?	Slates of Cant Hill and east of Dinham Creek.

According to the Survey the Pillow lavas of Pentire Head lie above the Portquin goniatite beds and below the Purple and Green Slates. If this is so they are underlain by beds of the Upper Middle Devonian and overlain by Frasnian beds of the Lower Upper Devonian. Whether they are of uppermost Middle Devonian age or lowermost Upper Devonian age or transitional still remains to be determined.

Dr. E. M. Lind Hendricks has suggested that the deposits in the Padstow area are a development of the Briovérien facies of Brittany

which is a deep-water facies characterized by a pelagic fauna. Certainly the facies is distinct from that developed at the same time in South Devon where the genera *Maenioceras* and *Wedekindella*, recorded here from the slates at Trevone and Portquin, occur in the Middle Devonian limestones of Wolborough and Barton.

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CORRESPONDENCE

TILLITE–GRANITE TRANSFORMATIONS

SIR,—We do not wish to make further comment on Dr. Bowes's reply (*Geol. Mag.*, 1956, p. 18), but should like to bring to notice that from his stratigraphical work in the Mt. Fitton–Mt. Painter region Dr. B. Campana of the South Australian Geological Survey has recently published [1] conclusions similar to our own.

16th April, 1956.

G. A. CHINNER.
M. SANDO.
A. J. R. WHITE.

REVIEW

PALÄONTOLOGIE UND PHYLOGENIE DER NIEDEREN TETRAPODEN. By FRIEDRICH VON HUENE. pp. xii + 716 with 690 text figures. Gustav Fischer, Jena. 1956. Price DM. 88.

This is a well-produced, generously illustrated account of the extinct amphibia and reptiles, written by a palaeontologist whose reputation has been established among the leaders of the subject for half a century. Professor von Huene, the first of whose three hundred and more publications appeared in 1899, is the foremost authority on the primitive archosaur reptiles, but his researches have ranged into almost every reptilian order and also into the extinct amphibia, and for him to have completed such a work as this at the age of eighty must be held to be a remarkable achievement. The subject is introduced by a discussion of the origin of the tetrapods ; there is an introduction to each order, practically every genus receives at least a mention, and the account is concluded by a discussion and an up-to-date list of references. The discussions are supported by diagrams illustrating taxonomic and morphological matters.

It is somewhat unfortunate that such a work should be published simultaneously with the corresponding volume of the *Traité de Paléontologie*. As is perhaps to be expected in a work of such magnitude carried out by a single writer, there are errors of reference and figures are sometimes ascribed to the wrong author. Scales are seldom given in the text figures and the index is unfortunately confined to generic names. Nevertheless, in the present state of flux of so many groups, this volume will be welcomed as a valuable contribution to the subject, and the author's opinion of the numerous problems which are involved will be of great interest to specialists.

F. R. P.

[1] CAMPANA, B. (1955). "The Stratigraphy of the Northern Flinders Ranges and the Alleged Granitisation of Tillite in the Mt. Fitton Area." *Austr. Journ. Sci.*, xviii, No. 3, pp. 75–7.

NOTICE

Zoological Nomenclature

Notice is hereby given that the possible use by the International Commission on Zoological Nomenclature of its Plenary Powers is involved in applications relating to the under-mentioned names included in Parts 1 and 2 of Volume 12 of the *Bulletin of Zoological Nomenclature*, both of which Parts have been published on 12th June, 1956:

(*a*) *Applications in Part 1*

Paradoxides Brongniart, 1822, validation of; *Olenus* Dalman, [1827], designation of type species for, in harmony with accustomed usage; *paradoxus* Linnaeus, 1759 (*Entomolithus*) suppression of; PARADOXIDEN Emmrich, 1844 (wrongly based on *Olenus*), suppression of (Class Trilobita) (Z.N.(S.)623).

tuberculatus Hall, 1859 (*Acidaspis*), validation of; *Acanthaloma* Conrad, 1840, suppression of (Class Trilobita) (Z.N.(S.)998).

Protopeltura Brögger, 1822 (Class Trilobita), designation of type species for, in harmony with accustomed usage (Z.N.(S.)1034).

(*b*) *Applications in Part 2.*

Trinucleus Murchison, 1839, validation of; *tuberculatus* Link, 1807 (*Trinucleus*), suppression of (Class Trilobita) (Z.N.(S.)926).

Illaenus Dalman, (1827), protection of by suppression of *Cryptonymus* Eichwald, 1825 (Class Trilobita) (Z.N.(S.)1068).

Any specialist who may desire to comment on any of the foregoing applications is invited to do so in writing to the Secretary to the International Commission (Address: 28 Park Village East, Regent's Park, London, N.W. 1, England) as soon as possible. Every such comment should be clearly marked with the Commission's File Number as given in the present Notice.

FRANCIS HEMMING,
Secretary to the International Commission on Zoological Nomenclature.

2nd June, 1956.

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LAPWORTH, C. 1878. The Moffat Series. *Quart. Journ. Geol. Soc.*, xxxiv, 240–343.

References should be cited in the text by author's name and date, with page reference if necessary, in brackets:—(Lapworth, 1878, p. 339).

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